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MAGMAS AND IGNEOUS ORE DEPOSITS.[1]

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PART I.

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THE purpose of this paper is to discuss the various processes which have been active in the formation of ore deposits by carrying and depositing material from magmas.

[1] Although this Manuscript from the pen of Professor Vogt was submitted in English, painstaking revision was necessary for publication. This arduous task was willingly undertaken as a labor of love by our associate, Professor R. W. Brock. Some changes were made by the Editor.—EDITOR.

[2] The writer is indebted to the Foundation of the Technical University of Norway for financial aid in connection with investigations and preliminary work.

MAGMATIC DIFFERENTIATION.

In a study[3] of "the anchi-monomineralic and anchi-eutectic igneous rocks" the writer concluded "that the composition of the igneous rocks—or in other words, the magmatic differentiation—might be explained by the supposition that the physical-chemical laws which govern differentiation lead to the same result as those which exist for the phases liquid: solid. Magmatic differentiation is the displacement of the components which should first crystallize by cooling."[4] This displacement or "wandering" is now explained by *gravitative differentiation,* which has been studied particularly by American geologists in recent years. Through early crystallization and consequent gravitative differentiation the magma becomes divided into two parts, one part enriched in the constituents of the crystals, the "proto-enriched magma," the other impoverished by their removal and consequently enriched in the eutectic, the "eutectic enriched magma" or "rest magma."

When olivine crystallizes from a magma, the first mix-crystals to separate contain a relatively large proportion of the constituent Mg_2SiO_4, with a very high melting point, and a relatively small proportion of the constituent Fe_2SiO_4, with a relatively low melting point. As crystallization-differentiation advances, and the resulting olivine concentrates in a portion of the magma, that portion becomes richer in Mg_2SiO_4 and poorer in Fe_2SiO_4, until it becomes a dunite consisting almost exclusively of olivine with only from 7 to 10 per cent. Fe_2SiO_4 (stoichiometrically).

Similarly the high melting component An is enriched in the first segregated plagioclase. Starting from a parent magma with plagioclase components in about the proportion 30 per cent. An to 70 per cent. Ab, after repeated crystallizations and resorptions of the subsiding plagioclase crystals it becomes an anorthosite magma, with from 50 to 60 per cent. An and occasionally even from 70 to 85 per cent. An.

The mix-crystal minerals, which constitute the anchi-mono-

[3] *Kristiania Videnskabsselskabs Skrifter,* 1908. (anchi = almost.)
[4] Report of the XI. Internat. Geol. Congress, Stockholm, 1910.

mineralic rocks—anorthosite, dunite, bronzite, and diopside rock —resulting from an advanced differentiation in the *proto* direction, are characterized throughout by the pronounced enrichment of the high-melting mix-crystal component (An, Mg_2SiO_4, $MgSiO_3$, $CaMgSi_2O_6$ respectively) concentrated in the first crystallizing mix-crystal.

In the restmagma rocks, of an almost eutectic composition, with the alkaline granites (73 to 75 per cent. silica) and the alkaline syenites (pulaskite, etc.) as the most important examples, there are mix-crystal minerals characterized by enrichment of the *low* melting component and rather low content of the high melting component. A prominent large scale example is the high percentage of Ab and the low percentage of An in the plagioclase of the alkaline granites and syenites. The monoclinic pyroxenes of these and related rocks are often rich in the ægirite silicate, $NaFeSi_2O_6$, melting at a relatively very low temperature, and poor in the high melting diopside silicate, $CaMgSi_2O_6$. The amphiboles of the same rocks also carry a rather high percentage of the low melting arfvedsonite and riebeckite silicates, rich in sodium. The micas of the same rocks, often lepidomelane, are rather poor in MgO, but rich in FeO and Fe_2O_3. We may also note the rather high content of $FeSiO_3$ (about 50 per cent.) in the orthopyroxene of the hypersthene syenites and trachytes.

Graphic granite, formed by a simultaneous crystallization of feldspar and quartz, contains about 74.5 per cent. silica when the feldspar is a microcline, and about 76.5 per cent. silica when the feldspar is an oligoclase or oligoclase albite. A medium admixture of microcline and oligoclase may give 75–76 per cent. silica. Adding to this 1 or 2 per cent. of ferromagnesian or ferrosodium silicate (biotite, ægirite, etc.) and 1 or 1.5 per cent. magnetite (a trace of apatite, etc.) we get the "ternary" granitic eutectic, carrying 74–75 per cent. silica.

If we compare the relatively basic granites with about 65 or 66 per cent. silica with the ordinary acid granites, with about 74 or 75 per cent. silica, on the average in the latter we notice a very considerable decrease of MgO, FeO + Fe_2O_3, CaO, TiO_2 and

P_2O_5. The average decrease is in the proportion of one to one third, one fourth, one fifth, and even one tenth for some compounds. An elementary calculation proves that the acid granites cannot have been formed by the addition of silica to the more basic magmas, but by the subtraction of the components of the compounds given above. These compounds enter into the minerals (apatite, magnetite, ilmenite, ferromagnesian or ferromagnesium-lime silicates and An of the plagioclase) that begin to crystallize at a rather early stage of the solidification, before quartz has begun to crystallize. This phenomenon, in connection with other facts, justifies the conclusion that *acid granites represent the restmagma at an advanced stage of gravitative differentiation.*

According to numerous analyses, granites with 70–71, 71–72, 72–73, 73–74, and 74–75 per cent. silica are about equally common, but those with 75–76, and still more with 76–77 and 77–78 per cent. silica, are rare.[5] Thus the percentage of 74 or 75 for silica in the granites—corresponding to the granitic eutectic—appears to be, genetically significant.

The eutectic boundary, at 74–75 per cent. silica, is surpassed in but few cases, and these are due, probably, to some of the silica of the magma entering into such independent compounds as $H_2SiO_3 \cdot nH_2O$ that only at a late stage of the solidification break up into SiO_2 and H_2O.

In the quartz-bearing norites, gabbros and syenites, with 0.5, 1, 2, 3, or 4 per cent. quartz, we often observe restmagma dikes of granitic composition carrying up to about 25–30 per cent. quartz. The plagioclase of these dikes is without exception much poorer in An than the plagioclase of the mother rocks. By a calculation the writer has estimated that these granitic dikes represent the restmagma squeezed out at a stage when 80, 90, and even up to 93 per cent. of the mother rock had already been solidified.

In the comagmatic provinces, consisting of rocks with about

[5] See Fig. 7 in my treatise of 1908 and Fig. 2 in my review in *Kristiania Videnskabsselskab*, 1923.

60 per cent. silica, the granites belong to the last stage of the sequence of eruption. This fact best accords with the sequence of the crystallization of an intermediate acid magma, which, independent of the original relation between Or, Ab, An, ferromagnesian silicates, titanic iron oxides, etc., must give a granitic restmagma. The theory requires that the granites begin to crystallize later than the other more common rocks (gabbros, syenites, monzonites, etc.), which is also the fact.[6] As a consequence of our theory, we may point out that the magmas of the granites may never have been superheated.

ALTERATION OF THE COMPOSITION OF THE RESTMAGMA BY ADVANCING CRYSTALLIZATION.

The following examples (Table I.) taken from Norwegian localities illustrate how the composition of the restmagma may differ from the mother rock.

The "normal" anchi-eutectic restmagmas (illustrated by analyses $1b_2$, $2b$, $3b$), resulting from magmas of granitic, syenitic, monzonitic, dioritic, and gabbroidic composition (thus here peridotites, pyroxenites, and anorthosites are disregarded) are characterized by several common features: a very low percentage of phosphoric and titanic acid, a relatively low percentage of magnesia, as this compound enters principally into the first crystallizing minerals, a rather low percentage of CaO and rather low content of An in the plagioclase, some alkalies, especially entering into Ab and Or, about 1 or 1.5 per cent. Fe_3O_4, and some FeO and Fe_2O_3 entering into the FeMg or NaFe silicates, rather poor in MgO, but rather rich in $FeO + Fe_2O_3$.

To illustrate the problem of rare compounds we will mention some facts from the layers of sodium and potassium salts (chlorides with sulphates, etc.) resulting also from a process of crystallization.[7] Bromine enters into the first crystallizing salt, sodium chloride to a much smaller degree than its ratio to chlo-

[6] *Jour. of Geol.*, 1923, pp. 415–419.

[7] See Boeke-Eitel, "Grundlagen der phys.-chem. Petrographie," sec. edition, 1923, pp. 499–502, and the original investigations quoted here.

rine in the original ocean water. It is thus concentrated in the mother-liquid from the beginning of evaporation until it enters into the separated minerals (carnallite, etc.). Iodine, on the other hand, does not perceptibly replace chlorine and bromine idiomorphically, and is thus concentrated in the very last mother-liquid.

TABLE I.

	1*a*.	1*b*$_1$.	1*b*$_2$.	2*a*.	2*b*.	3*a*.	3*b*.
SiO_2	53.6	61.28	66.3	54.55	66.50	63.5	75.1
TiO_2	0.8	0.40		1.40	0.70	0.5	tr
Al_2O_3	9.9	21.58	19.4	19.07	17.81	17.5	13.4
Fe_2O_3	0.4	0.22	0.6	2.41	0.67	1.0	1.9
FeO	11.2	1.59	0.7	3.12	none	2.0	
MnO	0.4	0.20		0.17	0.20	0.2	
MgO	15.8	1.85	1.2	1.98	0.18	0.7	0.05
CaO	4.1	7.51	4.7	3.15	0.85	1.0	0.25
Na_2O	1.7	4.44	5.6	7.67	7.52	6.7	4.3
K_2O	0.7	0.74	1.3	4.84	5.53	6.1	5.0
P_2O_5	0.3	0.52		0.74	0.016	(0.08)	0.00
H_2O	1.0	0.40		0.72	0.50	0.7	
Total	99.9	100.77	100.0	99.82	100.46	100.0	100.0

No. 1, from Romsaas, of quartz norite, locally with orb structure (*Jour. of Geol.*, 1921, p. 430–435).

No. 1*a*, average of analyses of the quartz norite (disregarding a little pyrrhotite).

No. 1b_1, analysis by C. Bugge of the interstitial mass between the first crystallized orbs of hypersthene, representing a stage when the restmagma amounted to about 30 per cent. of the total rock.

No. 1b_2, small pegmatitic dikes, the analysis of the mineralogical composition (8 per cent. biotite, 73 per cent. plagioclase, and 19 per cent. quartz) representing a stage when the restmagma amounted to only a small percentage.

No. 2, from Lardal (see W. C. Brøgger, "Das Ganggefolge des Lardalites," 1898).

No. 2*a*, lardalite.

No. 2*b*, lestiwarite (with revised determinations of P_2O_5, Fe_2O_3, FeO, and Al_2O_3 at the chemical laboratory, Trondhjem), representing Brøgger's ultimate link of the leucocrate series, identical with the ultimate link of the restmagma dikes.

No. 3, from the quarries of nordmarkite, Aarvoldsaas (Tonsenaas), near Kristiania.

No. 3*a*, an average of two analyses of the nordmarkite (see W. C. Brøgger, *Zeits. f. Kryst. Min.*, XVI., 1890, p. 54).

No. 3*b*, an average of several students' analyses of small dikes of granophyric aplite, representing a stage with 10 per cent. restmagma at the most.

As to the pegmatitic dikes, representing the restmagma at a more or less advanced stage of the solidification of granite and of nephelite and augite syenite, we first call attention to a negative phenomenon, the practically complete lack of minerals carrying nickel and cobalt and chromium. In the numerous precise-analyses in Brøgger's work [8] on the minerals from the nephelite and augite syenite pegmatites from Langesundsfjord, and in his paper [9] on the niobates, tantalates, etc., and in the paper of Brøgger-Th. Vogt-Schetelig [10] on the silicates of the yttrium and cerium series of the Norwegian granite pegmatites, we find in several minerals small amounts of SnO_2, WO_3, PbO and ZnO such as .1 to .2 per cent. In no case, however, do we meet with even a trace of NiO and Cr_2O_3, which are more abundant in the rocks than SnO_2, WO_3, ZnO, and PbO, and cobalt is only mentioned in a single case—as a trace in the rare mineral löllingite, $FeAs_2$, from Langesundsfjorden. The almost complete lack of nickel, cobalt, and chromium in the minerals of these pegmatites may be due to concentration in the first crystallizing minerals. There was thus practically nothing left for the ultimate residual magma.

On the other hand, compounds such as SnO_2, WO_3, ZnO, PbO, Nb_2O_5, Ta_2O_5, etc., enter into the first crystallizing minerals only to a relatively subordinate extent and may thus be concentrated in the residual magma in the same manner as the iodine and in part the bromine of the oceanic salt layers. Here we meet in general, with an enrichment of all those compounds which do not escape from nor enter into the first crystallizing minerals except to a relatively subordinate degree if at all.

"GAS AND MAGMA."

The critical temperature of pure water is, according to modern precise investigations, 374° (374.07–374.62°), and the critical pressure is 225kg. per sq. cm. (219 atmospheres). The critical

[8] *Zeits. f. Kryst. u. Min.*, XVI., 1890.
[9] *Kristiania Videnskabs Selsk.*, 1906.
[10] *Kristiania Videnskabs Selsk.*, 1922.

temperature and the critical pressure of liquids increase somewhat when they contain dissolved salts, such as NaCl, but the increase is not considerable. No investigations have been made as to water. In analogy with the results from other liquids and in accordance with the approximate theoretical formula which has been given for liquids in general, we may assume that the critical temperature of water, containing different salts in solution, does not rise higher than about 400° or 425°.

When a liquid, for example water, containing a salt in solution, is heated under high pressure above the critical temperature, the salt is also transferred to the gaseous condition.[11]

As to the condition in general between two substances, A and B, we may distinguish between two cases:

I. The critical temperatures of A and B (for example, lead and antimony) are not far from each other, and the "critical curve" of the mixture of A and B does not cut the curve of the gas phase. The system $A:B$ (x) by varying temperature (t) and pressure (p) is illustrated by a tx-diagram (Fig. 1), assuming a very high pressure perpendicular to the plane of the paper. M_a and M_b are the melting points of the two substances, and C_a and C_b their critical temperatures. Point m on the liquid phase (melt of 40 per cent. Pb and 60 per cent. Sb) corresponds with point n (gas of 55 per cent. Pb and 45 per cent. Sb) on the gas phase.

Along M_a to E we get a crystallization of A, along M_b to E the crystallization of B. E is the binary eutectic point, with simultaneous crystallization of Pb and Sb. The gas phase corresponding to the eutectic melt E has the composition F.

[11] The critical phenomena of two or more substances were investigated some years ago by the Dutch physicochemist A. Smits. The application of his general results on the magmas carrying volatile compounds have been especially worked out by Paul Niggli. See particularly "Die leicht-flüchtigen Bestandteile im Magma," Leipzig, 1920, and "Über magmatische Destillationsvorgänge," in *Zeits. f. Vulcanologie*, V., 1919. In "Grundlagen der physikalish-chemischen Petrographie" by Boeke (1905) and Boeke-Eitel (1923) an abstract is given on the investigations of Smits, Niggli, and others. See also Beyschlag-Krusch-Vogt, "Die Erzlagerstätten," II., sec. edition, 1921, p. 555 et seq., for review of lecture of Th. Vogt and papers of Niggli, and *Jour. of Geol.*, XXX., Nov.–Dec., 1922.

II. The critical temperatures of A and B (for example, H_2O and a silicate ($NaAlSi_3O_9$), assuming that these will not form a chemical compound at any temperature or pressure) are far from each other, and the "critical curve" cuts the gas phase curve (Fig. 2). We may here distinguish three temperature stages.

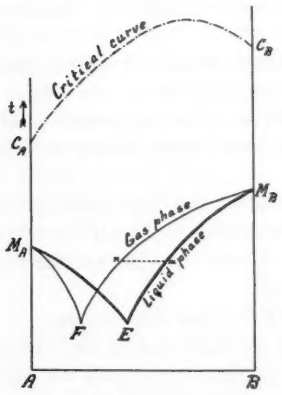

FIG. 1.

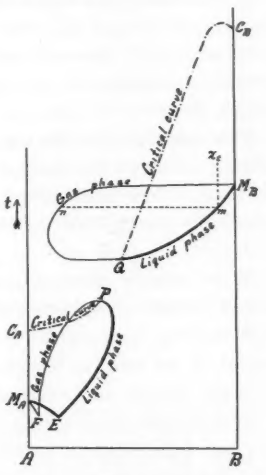

FIG. 2.

1. A small admixture of the light volatile compound, for example H_2O, decreases the melting point of $XA + (1-X)B$ and we get a crystallization of B, for example $NaAlSi_3O_8$, along the curve from M_b to Q.

Molten B has a very low gas tension. By cooling a melt of the composition Xt (for example, 98 per cent. $B = NaAlSi_3O_8$ and 2 per cent. $A = H_2O$) to point m on the curve M_b–Q we get three coinciding phases: crystals of B (pure albite), a melt of composition m, and a gas of composition n (consisting mainly of H_2O with a little $NaAlSi_3O_8$). By continued cooling we have a crystallization of B down to Q, and at this point the melt and the gas phase have the same composition.

2. Between Q and P there is a gas of A and B, and here the separation of a liquid is impossible. Only the gas and the crystal of B are stable in the presence of each other, and by diminishing the temperature or pressure, or both, B crystallizes directly from the gas.

3. At P we get a liquid consisting of A and B, and a crystallization of B takes place along the curve from P to the binary eutectic point E between A and B. The gas phase P–F corresponds to the curve P–E. It contains considerable A and only a little B.

The binary eutectic between A and B moves by a system (H_2O: silicate) close to the axis of A, the solubility of the silicate in water at a low temperature, such as room temperature, being practically disregarded. Point E thus almost exactly coincides with point M_a (Fig. 4).

As to ternary systems, consisting of one high melting component B and two light volatile components, A and A', or of two high melting components, B and B' and one light volatile component A, we refer to Niggli's work.

In the cooling of a magma there are thus three stages:

1. A magma field, M_b–Q, with crystallization of the silicates, etc., and with escape of volatile compounds, principally the rather light, but also some of the heavier volatile components.

2. A gas-field, Q–P, where only gas and crystal forms are stable in the presence of each other, and where a mineral may crystallize directly from the gas.

3. Finally, a field consisting of a liquid (for example, H_2O, CO_2, etc.) carrying in solution some of the high melting components.

We may, however, also mention the possibility of the formation of a compound between a silicate and a light volatile component at a rather high temperature and pressure, resulting in the disappearance of the gas phase Q–P—a compound such as $H_2SiO_3 \cdot nH_2O$, described below.

The light volatile compounds dissolved in the magma exist in the reciprocal solution in the same manner as the other solution

components. They thus exert no influence on the mix-crystal system, for example on the proportion between Ab and An in the crystallizing plagioclase, nor on the sequence of the crystallization between independent components, but they do effect a very considerable depression of the temperature of the crystallization of the silicates, etc., and this depression is nearly proportional to the quantity of the dissolved compounds, H_2O, CO_2, etc. In a melt of $KAlSi_3O_8$ and SiO_2 with some dissolved H_2O, the eutectic boundary between $KAlSi_3O_8$ and Qu is only slightly dislocated by the presence of more or less H_2O and other components. The composition of the graphic granite from granite-pegmatite dikes, crystallized at a great depth (or at a very high pressure) but with varying depths or pressures and thus with varying contents of H_2O in the magma, may thus not be absolutely constant, but vary only within narrow limits.[12]

Below is given (Table II.) the melting point (Mp), the boiling point (Bp), at the pressure of one atmosphere, and the critical temperature (Cp) of some substances.[12a]

TABLE II.

	H_2.	O_2.	N_2.	CO.	CH_4.	CO_2.	HCl.	HBr.	HI.	Cl_2.	CCl_4.
Mp.	−259	−219	−210	−207	−185	−57	−111	−86	− 50	−101	− 24
Bp.	−253	−183	−196	−190	−162		− 83	−69	− 35	− 34	76
Cp.	−241	−118	−147	−139	− 83	31	52	91	151	144	283

	H_2O.	CS_2.	H_2S.	H_2Se.	SO_2.	SO_3.	SiH_4.	SiF_4.	$SiCl_4$.	$SnCl_4$.	$TiCl_4$.	$AsCl_3$.
Mp.	0	−112	− 83	− 66	− 73	17	−185	−102	− 69	− 33	−25	− 18
Bp.	100	46	− 61	− 41	− 10	45	−112	− 65	57	112	136	130
Cp.	374	279	100	138	157	216	− 3	− 1.5	230	319	358*	356*

	PH_3.	PF_3.	PCl_3	SbH_3.	$SbCl_3$.	SbI_3.	$AlCl_3$.	AlI_3.	S.	Fe.	Pb.	Ag.
Mp.	−133	−160	−118	−91	73	167	(190)	185	[113]	1411	327	960
Bp.	− 86	− 95	76	−18	223	410	183	350	445	(2450)	1525	ca. 2000
Cp.	53		285		534	828	356	682	1040	calc. 3700		

* Doubtful.

12 Vogt, *Jour. of Geol.*, 1921, pp. 330–350.

12a See Landolt-Börnstein's "Physikalisch-chemischen Tabellen," fifth edition, 1923.

	Mp.	Bp.		Mp.	Bp.
BCl_3	−107	12	BF_3	−127	−101
$SiCl_4$	− 69	57	SiF_4	−102	− 65
$TiCl_4$	− 25	136	TiF_4		284
$AsCl_3$	− 18	130			
			SbF_3	292	
$SbCl_5$	3	ca. 90	SbF_5	7	150
$BiCl_3$	232	447			
$AlCl_3$ [at 2 atm.	190]	112	SnF_4		705
$SnCl_2$	240	606			
$MoCl_5$	194	286	Mo_2OF_4	97	180
			MoF_6	17	35
W_2OCl_4	210	227	WOF_4	110	187
WCl_5	245	275			
WCl_6	275	347	WF_6	2	19.5
$NbCl_5$	194	240	NbF_5	75	217
$TaCl_5$	211	242	TaF_5	97	226
			UF_6	69	56
$FeCl_3$	303	rather light volatile			
$FeCl_2$					
$SnCl_2$	365	730	SnF_2	872	vol. at 900°
$CdCl_2$	565	ca. 900	CdF_2	1100	
$PbCl_2$	499	ca. 900	PbF_2	855	
Cu_2Cl_2	422	ca. 1000	Cu_2F_2	ca. 908	
$CuCl_2$	498	volat., splits to Cu_2Cl_2 and Cl_2			
AgCl	455	(rather high)	AgF	435	
CsCl	645	1300	CsF	684	1251
LiCl	605	ca. 1350	LiF	842	ca. 1675
KCl	768	1417	KF	846	1505
NaCl	801	1439	NaF	988	1695
$BeCl_2$	440		BeF_2	sublimes	at 800
$MnCl_2$	650		MnF_2	856	
$MgCl_2$	712		MgF_2	ca. 908	
$CaCl_2$	782		CaF_2	ca. 1330	
$SrCl_2$	870		SrF_2	ca. 900	
$BaCl_2$	955		BaF_2	1280	

As is well known, there exists a rough parallelism between the melting and boiling point and the critical point. The substances enumerated above give the following results, reckoned in absolute temperature.

Boiling Point.	*Critical Point.*
54– 88°	126–270°
144–172	271–558
187–223	304–503
240–290	489–647
346–458	807–1313

Most substances melting at 187 to 458° in absolute temperature, or from 88 to 185° from the orinary zero, have a critical temperature, in absolute measure, about 2 or 2.5 times as high as the melting point.

The chlorides and fluorides of boron and silicon have extraordinarily low melting and boiling points. Rather low figures characterize the haloides of arsenic, antimony, busmuth, titanium, and tin. It is unnecessary to repeat the details for the bromides and iodides, as they exert practically no influence on the magmatic extraction. The five and six valence chlorides, haloides, fluorides, and oxyhaloides of molybdenum, wolfram, uranium, niobium, and tantalium without exception have astonishingly low melting and boiling points.

Considerably higher figures are met with among the chlorides and fluorides of the common heavy metals, such as iron, manganese, zinc, cadmium, lead and copper. Many of these haloides when molten have a rather high gas tension; that is, they are volatile before reaching the boiling point. Some compounds, as is well known, pass by heating directly from the solid to the gaseous state, the boiling point at the pressure of 1 atmosphere being lower than the melting point.

The boiling points of the chlorides and fluorides of sodium, potassium and lithium lie at about 1350°–1440° and 1500°–1700° respectively. The gas tension of these haloides thus reaches at these high temperatures as much as one atmosphere. The gas tension of the fluorides of calcium and barium may still be considerably below one atmosphere at 1500°.

ESCAPE OF VOLATILE COMPOUNDS.

Experiments at ordinary pressure with several metals in the molten state demonstrate that the quantity of dissolved gases increases directly with the temperature. The solid metals also carry some gas in solution (solid solution) but this content is considerably lower than in the molten phase. Crystallization increases the tension of the dissolved volatile compounds owing to

their concentration in the residual magma. More or less of the gas must escape, and this escape takes place to a great extent spontaneously and spasmodically. Stirring the metal produces a violent escape. If the effective means to "destroy" or "bind" the dissolved gases in molten steel are not used their explosive escape at the beginning of solidification often takes place, and the resulting steel ingots often show successive zones of blisters owing to the disengagement of gases at separate stages of the solidification. Corresponding phenomena are exhibited by silver and copper in cooling.

Further, the quantity of gases dissolved in metals rises with the pressure—according to repeated investigations in proportion to the pressure with the one atomic gas and in proportion to the square root of the pressure with the two atomic gases. These general laws concerning gas in metals may be applied in the main to the magmas as many geological and petrological observations demonstrate.

The solidifying crust of furnace slags is often fractured by the escaping gas and then miniature "volcanoes" of flow are formed. This phenomenon, described in detail as early as 1858 by K. C. V. Leonhard and often observed by myself, demonstrates, that even a "dry" silicate melt at the pressure of only one atmosphere dissolves some gas, and that some of this gas escapes during the solidification.

During the crystallization of a magma the light volatile compounds conduct themselves in different ways:

1. If the gas tension of the mixture of the dissolved gases exceeds the external pressure, some gas escapes from the magma.

2. Some gas is enclosed in the crystallizing minerals as gas-inclusions.

3. Some gas enters as fix solution into the crystallizing minerals. The quantity calculated by weight of these "occluded" gases is, however, rather small.

4. Some gas may enter chemically into the crystallizing minerals, *e.g.*, H_2O in muscovite, biotite or hornblende, CO_2 in (primary) calcspar, etc.

5. Probably some gas may form separate compounds, which at a later stage of the crystallization split up, for instance $H_2SiO_3 \cdot nH_2O$ (treated below).

6. The rest of the gas remains in dissolved condition in the magma and is concentrated in the mother-liquid, at continuously decreasing temperature until it reaches point *Q* (Fig. 2).

The gas tension of the light volatile compounds, such as H_2O, CO_2, HF, HCl, H_2S, SO_2, etc., dissolved in a magma say at 1000–1200° on sufficient concentration may be enormously high —that of salts melting at say 500–700° rather low,—and that of salts boiling at say 150° below even one atmosphere.

In flows solidifying under a pressure of only a few atmospheres the removal of the gases from the magma, through free escape, inclusion in gas pores and occlusion, may keep pace with the advancing crystallization.

In a deep seated magma, on the contrary, the high pressure prevents the escape of the volatile compounds to a greater or lesser extent. The greater quantity of these gases tends to lower the temperature of crystallization, as a rule, more than the high pressure tends to raise it. Consequently with most magmas the crystallization interval of a flow may be at higher temperatures than that of the deep seated magma of the same chemical composition. This conclusion was emphasized by Th. Vogt,[13] who points out the different compositions of the mix crystals in the volcanic and plutonic rocks from the same magma. Taking the feldspars as examples: the percentage of Ab + An in the orthoclase (microcline, sanadine, kryptoperthite), and the percentage of Or in the acid plagioclase and anorthoclase are greater in the flows than in the corresponding deep seated rocks. And this may be due to the higher temperature during the crystallization of the feldspars in the flows as compared with that in the plutonics. Following the idea of Th. Vogt further, if we have two magmas, for example, of granite, of the same chemical composition, one consolidating at a rather shallow depth (say 1 km.) and the other at great depth (say 5–10 km.), the much higher external pressure in the latter prevents the escape of the volatile compounds until a relatively later stage of the solidification. And the composition of the escaping gases may at this stage be somewhat altered.

[13] *Loc. cit.*

We shall come back to this question in the chapter on the contact-deposits.

"MAGMATIC EXTRACTION" AND ALTERATION IN COMPOSITION OF THE LIGHT VOLATILE COMPOUNDS WITH ADVANCING SOLIDIFICATION OF MAGMAS.

In a paper some thirty[14] years ago I called attention to the vital importance of the "magmatic extraction"—viz. the chemical action of the dissolved rather light volatile compounds, such as H_2O, HF, HCl, H_2S, CO_2, etc.—on the (silicate) magma, some components of the latter being transformed to separate, more or less, volatile compounds.

We shall illustrate these processes by a well known example. $[SnO_2] + 4\ HF \rightleftarrows SnF_4 + 2\ H_2O$.

Assuming the same concentration of H_2O, HF and SnF_4 with decreasing temperature and pressure the reaction takes place from right to left; with increasing temperature and pressure and reverse reaction takes place from left to right,[15] *i.e.*, by decreasing temperature and pressure we get a "pneumatolytic" crystallization of cassiterite,[16] on the other hand by increasing temperature and pressure, as in the magmas, we get an "extraction" of SnO_2 by HF, giving SnF_4 and H_2O.

Supposing a constant temperature and pressure, in a magma, we have the equation of equilibrium

$$k = \frac{C_{SnF_4} C^2_{H_2O}}{C^4_{HF}} \quad \text{or} \quad C_{SnF_4} = k \cdot \frac{C^4_{HF}}{C^2_{H_2O}}.$$

SnO_2 in molten (or fix) phase—or existing in a combination with silica, etc.—do not enter into the formula.

We shall discuss the quantity of SnF_4 at varying proportions

[14] *Zeit. f. prackt. Geol.*, 1895, p. 473 et seq.

[15] We refer to the parallel reaction with SiO_2 and SiF_4 instead of SnO_2 and SnF_4 studied by E. Baur, "Chem. Kosmogr.," Munich, 1903, p. 58; *Zeit. f. Phys. Chem.*, 1904, 48, p. 483. See also R. Marc, "Chem. Gleichgewichte," etc., Jena, 1911, pp. 15–16, and the Handbook on Ore Deposits Beyschlag-Krusch-Vogt.

[16] We recall here the old classic experiment of Daubrée, producing cassiterite by the reaction of $SnCl_4$ and H_2O.

between the concentrations of H_2O and HF, the concentration [17] of $H_2O = a$ and that of $HF = (1/n)a$.

$$C_{SnF_4} = k \cdot \frac{\left(\frac{1}{n}a\right)^4}{a^2} = k \cdot \frac{a^2}{n^4}.$$

With concentrations of H_2O to HF in the ratios of 1 : 1, 1 : 10, and 1 : 100 respectively, we get the concentration of SnF_4.[18]

	1/1 HF	1/10 HF	1/100 HF
$C_{SnF_4} =$	$k \cdot \frac{a^2}{1}$	$k \cdot \frac{a^2}{10.000}$	$k \cdot \frac{a^2}{100 \text{ mill.}}$

Even if we have no knowledge of the value of the constant k the equation proves that in the presence of much H_2O in relation to HF, the reaction of HF on a magma, containing some SnO_2, yields practically no SnF_4. A notable production of SnF_4, presumes the presence of rather much HF in relation to H_2O.

We shall in a following chapter show that the pneumatolytic ore deposits, formed at the *very first* stage of cooling of the granite magmas, do not contain any tin at all—and that the cassiterite-deposits are due to gases, escaping at a *more or less advanced stage* of the solidification, when the quantity of HF may have increased in relation to that of H_2O. Of course HF may react not only on the magmatic tin, but also on many other elements—and besides we must consider the magmatic extractions due to H_2O, HCl, CO_2, H_2S, etc. At each stage of the solidification, an equilibrium must exist between the numerous volatile compounds and the (silicate) magma. And this equilibrium may change even very considerably—through the advancing crystallization.

The composition of the escaping gases is further a function of the external pressure in relation to the gas tension of the dis-

[17] The concentration means the number of gram molecules ($H_2O = 18$, $HF = 20$) in a given volume.

[18] At a very high temperature, especially above 1300–1500°, we may also note the dissociation of $2\,H_2O$ to $2\,H_2$ and O_2. The formula thus gets more complicated. This has, however, no decisive influence on the explanation below.

solved volatile compounds. The composition of the escaping gases may thus differ very considerably from that of the dissolved gases. And this differences may alter to a very considerable extent at each successive stage of the solidification.

PAUCITY OF LIGHT VOLATILE COMPOUNDS IN THE PROTO-ENRICHED ROCKS AND THEIR ABUNDANCE IN THE EXTREME RESTMAGMA-ENRICHED ROCKS.

As to the anchi-monomineralic rocks, taking the anorthosites as the most important representative, these rocks may have been formed by a repeated crystallization and resorption of an intermediary basic plagioclase. The content of original restmagma in these rocks amounts only to say 1/10 or 1/5, in relation to the added plagioclase. The content of light volatile compounds of the magma may have been reduced in about the same proportion, *i.e.*, the anorthosites—and the dunites, the bronzite and diopside rocks, etc.—may have crystallized from almost "dry" magmas. That this is the case, is verified by the petrographical and geological character of the anorthosites and the dunites.[18a] In connection with the low percentage of the light volatile compounds in the anorthosites (and the dunites) the fact is that so far as we know, ore deposits originating by the escape of gases are entirely lacking in connection with these rocks. Through gravitative differentiation in the restmagma direction the volatile compounds which do not escape during the process of differentiation, must become concentrated into the restmagmas, with the deep-seated granites, especially the alkaline granites, as end products. This theoretical conclusion is verified by abundant petrographical and geological observations, that prove the magmas of the granites to have carried, as a rule, the relatively highest content of light volatile compounds.

Referring further to the above quoted lecture (April, 1920) of Th. Vogt we note that dikes of granite pegmatite are lacking from granites solidified at a relatively shallow depth, but are

[18a] See the author's paper in *Kristiania Videnskabsselskab*, 1923, noted above and the more detailed paper sent to the same society for publication.

present, often in very great numbers, with granites solidified at a very considerable depth.

Corresponding dikes with pegmatitic structure are well known also in connection with monzonites, syenites, diorites, gabbros, etc., but on the whole are here less abundant than with many very deep seated granites, especially those of Archæan age. Also with the anorthosites we find though infrequently, pegmatitic dikes, of noritic or gabbroidic composition. This may depend on the relatively low content of H_2O, etc., in the anorthosite magmas.

PEGMATITIC DIKES CARRYING MINERALS DUE TO "MAGMATIC EXTRACTION."

Granite Pegmatites.—Some of these dikes carry practically no "rare minerals." On the other hand many, as is well known,[19] exhibit a very pronounced concentration of them, but the rare minerals themselves of the different dikes show great variation, as may be seen from the following miscellaneous examples.

Some granite pegmatites are rich in yttrium mineral (yttrofluorite with gadolinite, orthite, euxenite, fergusonite, xenotime, thalénite.[20] Other dikes are correspondingly rich in cerium minerals; others again extremely rich in scandium.[21] In some few Norwegian granite pegmatites thoruranite is present in fairly large amounts.[22]

Some dikes are rather rich in thorite.

In many Norwegian granite pegmatites *tourmaline* is almost completely lacking, on the other hand in other dikes, it is present in great abundance, sometimes even completely replacing the micas. In some dikes—espe-

[19] See above quoted papers of Brøgger (1906), of Brøgger-Th. Vogt-Schetelig (1922); and of Niggli, on the light volatile compounds of the magma (1920, pp. 165–191). If we restrict the term pegmatite to igneous rocks crystallized from liquid magmatic solutions yet carrying more or less rather light volatile compounds, the "apatite scapolite dikes" should be excluded and not included as they have been by Niggli, for these correspond geologically to the cassiterite veins of the Zinnwald type (see below).

[20] See above quoted paper by Th. Vogt.

[21] See above paper by Schetelig.

[22] An attempt was made to work one or two of these dikes for thoruranite but without commercial success.

cially in those rich in oligoclase (see Brøgger's above quoted paper)—we find much *beryl*, locally in such quantity, that several tons of beryl have been produced as a by-product in feldspar mining. As a rule this mineral is accompanied by *topaz*, sometimes also in great quantities. Besides beryl in a few dikes we find phenakite. Divers *lithium*-minerals (lithium-tourmaline and micas, spodumene, triphylite, etc.) are sometimes present in great amounts, while on the other hand they are completely lacking in perhaps the majority of granite pegmatites. Thus Brøgger in his paper of 1906 pointed out, that lithium-minerals—and cassiterite—up to that time never had been found in the granite pegmatites of Southern Norway.

In by far the most granite pegmatites cassiterite is, as just mentioned, completely lacking, and the inconsiderable SnO_2 in the average pegmatitic magma enters into the "rare minerals," such as fergusonite, columbite, blomstrandite, etc. (carrying in the most cases 0.2–0.8 per cent. SnO_2). On the other hand in some few granite pegmatites cassiterite is present in such quantity that the dikes have been mined for tinstone. It is usually, but not always, accompanied by considerable quantities of lithium minerals. In a few granite pegmatites wolframite is rather abundant, but in most dikes, it is completely missing, the inconsiderable quantity of WO_3 entering into some of the "rare minerals."

In the ordinary Norwegian granite pegmatites molybdenite, in small leaves, is a mineralogical curiosity. On the other hand, a few pegmatite dikes contain so much molybdenite that they have been mined for this mineral.[23]

Monazite, $(Ce_1r)PO_4$, xenotime, $(Y_1r)PO_4$, and apatite (Fl-apatite) are not unusual, though in small amount. In a few dikes the quantity rises, and I remember a spot in one dike from which several tons of apatite were mined.

Fluorine, as is well known, enters into a number of the above mentioned minerals (apatite, tourmaline, lithium-mica, muscovite, biotite, etc.).

The above minerals are all primary [24] and they crystallize as a

[23] To avoid misunderstanding we note that the most Norwegian molybdenite deposits are veins and impregnations, containing quartz, tourmaline, etc., geologically belonging to the below mentioned Sn-W-Mo-Be-Li-B-F group of veins.

[24] In the above list fluorite is not included though occurring in a few dikes in rather large masses, since it is possible that this mineral does not belong wholly to the magmatic solidification, but to a later stage (cf. *Q–P* and *P–E* on Fig. 2 and the explanation in the next chapter). As pointed out by Th. Vogt in his lecture of 1922 already referred to, the hydrothermal phase is represented in granite pegmatites. To illustrate, there is the pure albite in druses deposited in

rule at a very early stage of the solidification of the granite pegmatitic magma.[25] Therefore the material of the rare mineral or minerals characteristic of the dike must thus have been present in the pegmatitic magma before the commencement of solidification.

In common biotite-granite pegmatites, the biotite began to crystallize before the feldspar (microcline) and the quartz. Minerals such as thoruranite, fergusonite, xenotime, monazite, uranothorite, columbite, blomstrandite, gadolinite, etc., to a great extent occur as more or less well developed crystals within the biotite, *i.e.*, the crystallization of these minerals began still earlier than that of the biotite, though continuing into the biotite period.

From the granite pegmatite dikes at Syversvolden by Drammen, Norway, I have received large samples, showing rosette-shaped crystals of molybdenite with idiomorphic outlines against the mica (muscovite), the microcline and the quartz, proving the very early crystallization of the molybdenite. See also Fig. 261 and pp. 777–778 in Lindgren's "Mineral Deposits," sec. edit., 1919. Cassiterite occurs also in many granite pegmatites and is in every case a primary mineral.

The considerable quantity of one or several of the elements Sn, W, Mo, Li, Be, B, Y, Ce, P, etc. in some special granite pegmatite dikes, compared with the commonly low percentage or almost complete lack of the same elements in most dikes, can not be explained by the "normal" slight enrichment of the rest-magma by compounds not (or only subordinately) entering into its first crystallizing minerals. On the contrary, this phenomenon must depend on an *extraordinary* supply, in one dike of Sn, in another of Mo, etc. And further, considering the well known affinity between many of the minerals—cassiterite, molybdenite, tourmaline, divers lithium minerals, beryl, topaz, apatite, etc.—characterizing divers subclasses of the granite pegmatites, and the mineral association of the veins and impregnations of the Sn-W-Mo-Be-Li-B-F group of veins, we may conclude that the

crystallographic orientation on microcline and oligoclase; there is the muscovite in druses; there are the accompanying zeolites, etc.

[25] See W. C. Brøgger, *Zeits. f. Kryst. Min.*, XVI., 1890, pp. 155–157.

supply of Sn, Mo, Li, Be, B, etc., was due to a magmatic extraction *during the solidification* of the mother granite-magma, the rather light volatile compounds being concentrated in the rest-magma that is responsible for the pegmatites.[26]

THE THREE STAGES OF CRYSTALLIZATION.

(*a*) From a magmatic (liquid) solution, (*b*) from a gas phase, (*c*) from a hydrothermal solution (cf. M_B–Q, Q–P, and P–E, Fig. 2) illustrated by the nephelite syenite pegmatites of Langesundsfjord.

In his classic work on these dikes and their minerals Brøgger (1890) distinguished the following stages or phases:

(*A*) The Magmatic Solidification phase, covering the formation of the principal minerals (feldspar, nephelite with cancrinite, sodalite (with 7.31 per cent. Cl), ægirite, lepidomelane, barkevikite, magnetite) and of a lot of subordinate minerals (astrophyllite, wohlerite, mosandrite, etc.), carrying some fluorine or chlorine and some of them also B_2O_3, S or As.

(*B*) The Pneumatolitic Phase, during which the main pneumatolitic minerals were formed: fluorite, melinophane, leucophane, etc., carrying some fluorine, further cappelinite, homilite datolite, etc., all rather rich in B_2O_3, and some sulphides.

(*C*) The Hydrothermal Phase, responsible for the formation of zeolites, analcite, natrolite, desmine, apophyllite, etc.

(*D*) The Phase of fluorine carbonates, carbonates, etc., with the alteration of divers minerals to kaolin, chlorite, etc.

Thirty years afterwards Niggli, in his classic work on the light volatile compounds in the magmas (1920) gave the physico-chemical explanation:

Brøgger's phase *A* represents the common magmatic solidification,—his phase *B* represents, in the main, the crystallization from a gas phase (*Q*–*P*)—and his phase *C* (and *D* in part) represent the final crystallization of a hydrothermal solution (*P*–*E*).

[26] Vogt, J. H. L., in *Zeits. f. prakt. Geol.*, 1895, p. 473 et seq.

Brøgger's investigation now more than thirty years old still furnishes the best exposition of the complete process of mineral formation from a magma.

RELATION BETWEEN GRANITE PEGMATITE AND QUARTZ DIKES.

Many recent investigators have called attention to the intimate genetic connection between granite pegmatite dikes and accompanying smaller or greater masses of quartz, often occurring as typical injected dikes. This phenomenon I observed long ago in Norway—but without paying it any great attention. As an example I here reproduce (Fig. 3) an old drawing by myself

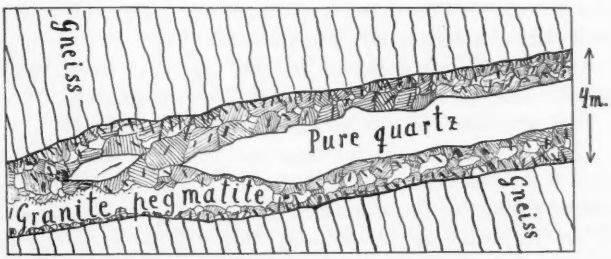

FIG. 3. Flat-lying dike of granite pegmatite, the central part consisting of pure quartz. From near Arendal, Norway.

(copied from my notebook July 22, 1884) from a locality in the neighborhood of Arendal, in the Archean formation of Southern Norway.

It is evident that the granite pegmatite and the quartz-dike originated from the same mutual solution. In the first stage the mica, feldspar and quartz crystallized—the two latter partly as graphic granite—and lastly the masses or dikes of practically pure quartz, sometimes, as in the above case (Fig. 3), filling the central part of the mutual dike.

O. Mügge observed long ago[27] that the quartz of the graphic

[27] *N. Jahrb. f. Min.*, Festband, 1907, 181, see also *Centr. Bl. f. Min.*, 1921, pp. 609–615, 641–648.

granite in an α-quartz formed at high temperature. F. E. Wright and E. L. Larsen [28] verified this observation and further proved that the quartz of the younger masses or dikes, accompanying the granite pegmatites, on the other hand is a β-quartz. The inversion point between α- and β-quartz has been determined by Wright and Larsen to be $575 \pm 2°$ at the pressure of one atmosphere. At a very high pressure we may presume a somewhat higher temperature,[29] say 600–625°.

The original granite-pegmatite magma, rather rich in H_2O (and other light volatile compounds), that lower the temperature of the crystallization, began to crystallize at a somewhat higher temperature, say about 700 or 750° with the separation at first of some mica etc. The crystallization of the graphic granite took place at a temperature still above 600–625°. The residual material of the quartz-masses or dikes may have cooled below this and first solidified at a somewhat lower temperature.

How are these quartz-masses or dikes to be explained?

If the physicochemical case illustrated by Fig. 2 should be applied to the system SiO_2–H_2O, at the interval between Q (representing the end of the solidification of the graphic granite, etc., of the pegmatite, above—probably only a little above 600 or 625°) and P (the critical temperature of H_2O containing some dissolved salts, a little above 374°, say 400 or 425°) we might get a gas phase, and at a still lower temperature this might pass over into the hydrothermal phase.

Owing to the extreme high pressure, the material of the gas phase, existing during the very considerable period of time required for a temperature decrease of about 200°, ought to have been injected into all cracks, pores, etc. of the wall rock. We find no indication of this whatever. Thus the geological field observations prove that the system SiO_2–H_2O cannot belong here.

Because the degree of electrolytical dissociation of H_2O increases very considerably with the temperature, Svante Arrhenius

[28] *Amer. Journ. of Sc.* (4), 27, 1909, p. 421 and *Zeitschr. f. anorg. Ch.*, 68, 1910, p. 338.

[29] See my paper in *Journ. of Geol.*, 30, 1922, p. 619.

long ago [30] concluded that H_2O in the magmas exists partly as an acid, such as H_2SiO_3.

In explaining some petrographical phenomena, relating especially to the sequence of crystallization of the granites and to the composition of some granitic magmas carrying more than 75 per cent. SiO_2 (and thus surpassing the "granitic eutectic") I arrived at the same result.[31]

Johann Jakob (of Zürich) has applied Werner's "theory of coördination" to the minerals and magmas.[32] He points out that at high temperature and pressure two (or more) molecules of H_2O must be added to one molecule of SiO_2, and that in the system SiO_2–H_2O a critical phase (Q–P) between the two fields of solutions (above Q, resp. below P) never may occur.

Thus (according to Jacob) by the cooling of a quartzitic injection, at a very high pressure, we may get only liquid solutions, which at the higher temperature may be called a melt solution or an "aqueo-igneous" solution, and at a lower temperature, a hydrous solution.

We may presume then, on account of petrographical as well as chemical or physicochemical reasons, that the granitic magmas, besides the components of Fe_3O_4, Fe, Mg silicates, Or, Ab, An, and SiO_2 ("free silica") also carried a component such as $SiO_2 \cdot nH_2O$ or $H_2SiO_3 \cdot nH_2O$ (where n may be 0, 1, 2, or a still higher figure) and further dissolved gases, H_2O, CO_2, etc.—the quantity of the separate component $H_2SiO_3 \cdot nH_2O$ depending on the magmatic equilibrium. We may presume further that the quantity of this component increased with the pressure.

During the solidification of a granite magma dissolved H_2O may escape, resulting in a gradual splitting up of the component $H_2SiO_3 \cdot nH_2O$ [33] to SiO_2 and H_2O.

[30] "Geol. Förken-Förk," 1900, p. 415. *Lehrb. d. kosmischen Physik*, 1903, I., pp. 312–314.

[31] "Die Silicatschmelzlösungen," II., 1904, p. 219. *Tscherm. Min. petrogr. mitt.*, XXV., 1906, p. 412, and later papers.

[32] "Zur Theorie der magmatischen Mineralisotoren," *Zeitschr. fur anorg. Ch.*, 106, 1919, pp. 229–267.

[33] The late magmatic formation of myrmecite may perhaps depend on corresponding alkaline components.

A component such as $H_2SiO_3 \cdot nH_2O$ together with the dissolved H_2O, may be concentrated at high pressure in the residual pegmatitic magma. And by this crystallization there finally may result a separate magma, $H_2SiO_3 \cdot nH_2O$ with more or less of dissolved H_2O, CO_2, etc. And this, by continued cooling and resulting escape of H_2O, may give rise to the separate masses or dikes of β-quartz.

TEMPERATURES AT WHICH IGNEOUS ROCKS CRYSTALLIZE.

Calculating at one atmosphere pressure and disregarding the H_2O content, etc., crystallization may begin at the following temperatures.

Anchi-monomineralic Rocks.

Dunite	About 1500°, occasionally 1550–1600°
Other peridotites with less olivine	About 1400°
Bytownite rock	About 1475–1500°
Labradorite rock	About 1400–1450°

Anchi-eutectic Rocks.

Gabbro and norite	About 1250°
Diorite	About 1200°
The most common syenites	About 1100°
The ordinary granites	About 1000° (in part a little less)

To the above, two corrections are necessary, one for pressure which causes a rise in the temperature of crystallization and one for the content of water and light volatile compounds which lower it. The effect of pressure is small, that at a depth of from 5 to 10 kms. amounting to about 50° only. The effect of the dissolved water etc. in magmas rich in them, such as the granite magmas, may be considerable. With the anorthosites and dunites poor in water, etc., the two corrections, in opposite directions, may neutralize each other; with the deep seated gabbros, diorites, syenites and granites, as already mentioned (see page 221) it may be presumed that the decrease due to water, etc., will more than offset the increase due to pressure and therefore that as a rule these rocks will not begin to crystallize until the temperature of the magma drops below the above figures.

The final crystallization, as a rule, may take place at a eutectic or at a eutectic boundary at a diminished temperature.

We shall give an estimate of the crystallization temperature of some eutectics, calculated at one atmosphere pressure and without H_2O, etc.:

Acid plagioclase (Ab with very little An): augite (diopside in a quantity of a couple or some few per cent.).....About 1050–1100°
K, Na feldspar: aegirite (cfr. analyses nr. 2b).....About 1000–1050°
Orthoclase (microcline): quartz and albite: quartz (graphic granite).....About 950–1000°
Or: Ab: quartz, etc. (the "ternary" granitic eutectic).....About 900–950°

These figures may be somewhat diminished owing to the H_2O, etc.

I have stated above that the graphic granite of the granite pegmatites, relatively rich in H_2O, etc., may have crystallized at a temperature somewhat above 600–625°, say about 650–700°. In the ordinary granites, with somewhat lower contents of the light volatile compounds than the pegmatites, the temperature of the final eutectic may have been somewhat higher—thus according to one working method somewhat above 650–700° and according to another working method decisively lower than 900–950°, thus about 750–800°.

In diorites, monzonites, syenites and gabbros-norites carrying some quartz, even less than 0.5–1 per cent., we get a restmagma of granite-eutectic composition. The final crystallization of these rocks may thus take place at about the same temperature as that of the ordinary granites.

Thus point *Q* (Fig. 2) of all these rocks may lie at approximately 750–800°.

(*To be continued in No. 4, due June 15.*)

GEOCHEMICAL RELATIONS BETWEEN PETROLEUM, SILICA, AND WATER.[1]

P. G. NUTTING.

PETROLEUM and water are slightly soluble in each other and components of each enter into chemical combination under certain conditions of temperature and pressure. Silica is a powerful adsorbent of water and of certain components of petroleum. Surface reactions between the silica and adsorbed layers undoubtedly occur in many cases. The equilibrium existing between the several components may in some cases be profoundly affected by contact with silica and silicates. The problems connected with the displacement of petroleum by gas, water, and water solutions depend largely upon selective adsorption and are of considerable economic importance. The evidence here presented and discussed relates largely to the economic and geologic aspects of relations rooted deeply in hydrocarbon, water, and silicate chemistries. Many of the conclusions reached are tentative at best and must remain so until more is known of the composition of petroleum and of the structure of the various silicas and silicates.

WATER AND PETROLEUM.

Water is well known to be slightly but definitely soluble in petroleum and in its constituents to the extent of about .02 per cent. at ordinary temperatures and pressures. This solubility is roughly the same in light, medium and heavy components (gasoline, kerosene and lubricating oil). The solubility of oil in water is of the same order and likewise nearly indifferent to oil density or saturation. If a bed of clear sand be covered a few millimeters deep with fresh water, then crude oil poured on the water, droplets of oil will be seen forming on the surface of the

[1] Published by permission of The Director, U. S. Geological Survey.

sand in the course of a few days, these droplets being of the same color and apparent composition as the crude above. This oil could reach the sand only by going into solution and migrating downward through the water. Wet sand attracts and holds oil for reasons discussed below. Saturation is attained only slowly in either case—in from 4 days to 2 or 3 weeks under ordinary conditions.

What appears to be the hydrolysis of crude petroleum by water is very pronounced though slow and leads to some peculiar phenomena. If crude oil be placed on water and allowed to stand for months, a light brown skin gradually forms at the interface and the oil thickens somewhat throughout. If sand be dropped in, it will be retained by the interfacial membrane as in a hammock. Water is slightly dissociated into H^+ and OH^- ions. My theory is that the terminal H atoms of the chain hydrocarbons are replaced in part by the OH^- from the water,

$$H(CH_2)_n \cdot (H \rightleftarrows OH),$$

forming the higher alcohols but slightly soluble in either water or oil. The carbon atom is notoriously indifferent as to whether it is bonded with H, OH or even another C atom.

Cook's much discussed experiment [2] appears to be merely a special case of such hydrolysis, the oil being thickened through long contact with water. The phenomenon is but slightly affected by temperature. In the lighter hydrocarbons such as methane and ethane the H atoms are more strongly held than in those of higher molecular weight. The reaction is inhibited by dissolving the salt of a strong base and weak acid, such as sodium carbonate, in the water, the Na presumably holding the OH in the water. Solutions of strong alkalies and strong acids react with oil in a variety of ways more or less familiar to organic chemists.

WATER AND SILICA.

Silica in its various forms may be almost without effect on petroleum, it may filter it (as regards color and saturation), or

[2] ECON. GEOL., vol. 20, Nov., 1925.

it may break up even a saturated, very stable hydrocarbon like paraffin, according to previous water and heat treatment. It may act as a catalyst in assisting in shifting equilibria, or it may react with certain components of petroleum. The problem is a complex one and scores of experiments were required to unearth the underlying principles.

A silica surface, exposed to air of ordinary humidity (40 per cent.) will adsorb a coat of moisture about .04 μ (4×10^{-6} cm.) or roughly 100 molecules deep. For ordinary fine sand this amounts to about 1 mg. per gram of sand, an amount readily determined by weighing on a good balance. The thickness of the adsorbed layer does not vary greatly with the humidity, a desiccator takes off only about ¼ of it while high humidities fail to double it. If removed by heating to a red heat, it returns rapidly after cooling and is fully formed in an hour or two.

The ratio of adsorbed moisture to silica of course increases as the size of particle diminishes. Bentonite, exposed to air of 40 per cent. humidity, carries about 15 to 20 per cent. moisture removable by heating, the particles being but a few microns in diameter.

It may be shown that this adsorbed film exists even when silica is immersed in water. A sample of sand of average diameter 0.3 mm. was divided into two portions and one half further reduced to 0.08 mm. average diameter. A careful determination of densities immediately after heating showed the density of the more finely divided silica to be between 1 and 2 per cent higher than that of the coarser, due presumably to an adsorbed layer more dense than water caused by close packing of staggered H and OH ions. From the rate of settling of bentonite in water it may be deduced that each particle carries with it an attached layer of water at least 20 molecules deep. Silica gel will set when the water ratio is as high as $300H_2O \cdot SiO_2$. Assuming that the adsorbed layers are then in contact, the layer of water more or less firmly attached to each SiO_2 molecule is about 10 molecular diameters thick.

According to this evidence, a natural assumption is that the H^+ and OH^- ions are arranged thus over a silica surface wet with water

H	OH	H	OH
OH	H	OH	H
H	OH	H	OH

Silica

Boswell and his students have made a similar assumption regarding water adsorbed by the oxides of aluminum and other metals. Sand grains thinly coated with ferrous aluminum silicate were found to behave toward water and oil much the same as clean sea sand.

As regards the silica molecule SiO_2, $O = Si = O$, the simplest modification possible is the addition of a single H atom forming the siloxyl radicle SiOOH, $O = Si—O—H$, having an open bond and being exhibited in such organic silicates as $H_3C \cdot SiO \cdot OH$, methyl siloxylate. The three silicic acids

$$\begin{array}{c} O \\ \| \\ HO—Si—OH, \end{array} \quad \begin{array}{c} H \\ O \\ HO—Si—OH \\ O \\ H \end{array} \quad \text{and} \quad \begin{array}{cccc} H & H & H \\ O & O & O \\ HO—Si—O—Si—O—SiOH \\ O & O & O \\ H & H & H \end{array}$$

H_2SiO_3, H_4SiO_4 and $(n + 1)\ H_2O \cdot nSiO_2$ are disavowed by some chemists because they take on an almost indefinite quantity of water.

If water be driven or drawn from these "silicic acids," open Si and O bonds will be left in about equal numbers. The monosilicic acids dried, thus tend toward $O = Si = O$ and insolubility. The same molecules in water, constantly interchanging their H and OH with the water, tend to couple up in chains of polysilicic acid since the chain form is more stable and permits less hydrolysis. Hence the best silica gels are made by using quite dilute solutions, thus preserving mobility until the incipient hydrolysis has brought about the chain or "brush pile" struc-

ture. A good gel is a brittle solid though it contain 90 to 99 per cent. water. Of this about 23 per cent. is molecular water, the remainder adsorbed. If silica be precipitated from rather strong solutions of acid and silicate, the silica is precipitated in flocculent form from which a large percentage of the water may be pressed.

The desiccated gel behaves very differently toward oil than the dried precipitated silica, the latter merely filtering it while the former breaks it down. In the chain structure, double bonding is limited or inhibited by the structure itself while in single molecules it is not. The optimum water content (for maximum activity), about 4 per cent., corresponds to a ratio of about 1 water molecule to 8 of silica. This amount of water is apparently just sufficient to prevent a general double bonding taking place, that is a relapse to the inactive O = Si = O form.

Freshly crushed quartz or fresh sea sand is highly inactive but these materials after standing some days or weeks in contact with water containing but a mere trace of dissolved salt become active like ordinary oil sands. Adsorbed water containing hydrolized salts evidently has the power of opening up the O = Si double bonds on the surface of silica.

PETROLEUM AND SILICA.

If an oil saturated oil sand be crushed, then thoroughly washed in benzol and ether and dried, it will be found to contain about 2 mg. per gram of sand of hydrocarbon material removable only by heating to a high temperature. The washing must of course be complete and adsorbed moisture avoided or corrected for. This result indicates that a silica surface has the power of strongly absorbing or of combining with at least certain components of petroleum.

Repeating this experiment with an artificial silica having a surface area per gram at least 100 times as great as had the oil sand, 21 per cent. removable only by burning was found. Using instead of crude petroleum, a heavy water white extract (laxative) to saturate the silica (also water white), transparent dark brown

grains were obtained, indicating a reaction between oil and silica. Even boiling in tetrachlorethane failed to lighten this color. Heating to 500° at low pressure for an hour failed to distill the brown material. The distillate was light brown, the grains became nearly black. Subsequent heating to bright red in a platinum crucible turned the grains jet black. They could not then be burned clear. This experiment was repeated with paraffin instead of oil, with a similar result.

This surface reaction between silica and hydrocarbon is apparently a removal by the silica of the end H from a hydrocarbon chain to form a siloxyl radicle which in turn unites with the body of the chain. It may be represented thus,

$$H(CH_2)_nH + SiO_2 = H(CH_2)_n \cdot SiOOH.$$

This is an alkyl siloxylate, several of which are known to organic chemists. There are of course many other possible reactions but the one cited appears to be of the simplest type. Given sufficient time, similar reactions would doubtless take place at ordinary temperatures.

The filtering action of silica and silicates on petroleum is quite varied. Every oil sand tried, when crushed, washed, and freshly heated to drive off most of the adsorbed moisture, proved a fairly good filter, the first oil through being nearly colorless and followed by canary yellow and red oil. The merest trace of acid or alkali left on the sand from the washing before drying, completely alters its filtering properties.

The colloidal "silicates" of all the metals, precipitated from salt solutions by water glass, (Cu, Mg, Zn, Al, Pb, Ur, Mn, Si, and Fe, were tested), with the exception of those of the alkalis (Na, K) and alkaline earths (Ca, Ba), filtered well and about the same as filters of precipitated silica and the natural filtering materials; fuller's earth, bauxite, bentonite, serpentine, green sand, ferric oxide, etc. In a typical case, using a 10-inch column of filtering material and a Bradford oil, 2 inches of oil would come through colorless, 3 inches canary, 5 yellow and 8 red. A slight trace of acid (remaining) on the filter improves its action,

alkali destroys it. A filter freshly and thoroughly dried gives much more colorless oil and less colored than one that has adsorbed 10 or 15 per cent. moisture.

Polysilicic acid in chain form $(n + 1)\ H_2O \cdot nSiO_2$ is about 23 per cent. water. This percentage of water was found to be the upper limit of filtering action as it is the lower limit of solubility in acid. The best filtering dryness (about 3.5 to 4 per cent.) is roughly the lower limit of solubility in alkali. Below 3 per cent. it rapidly approaches quartz in properties as water content is reduced.

Desiccated colloidal ferric hydroxide is an excellent filter except that, not being susceptible to chain structure like silica, it cannot be made porous and when finely powdered it is slow. In its action on oil it is similar to silica, and it may be supposed that partial dehydration leaves one open Fe bond and one oxygen bond,

$$\begin{matrix} & OH & & \\ Fe & OH & —H_2O \text{ leaves} — Fe & \begin{matrix} OH \\ O— \end{matrix} \\ & OH & & \end{matrix}.$$

The silicate of iron, if precipitated from solution so dilute that the gel sets only after several hours and then dried at a high temperature, may be made so active as to break down and darken the oil instead of filtering it. Silica or silicates so active as to break down oil, still retain this property even if previously saturated with heavy colorless oil or even with moisture.

The theory of filtration of oil by silica and silicates must remain obscure until more is known of the chemical composition of petroleum. The paraffin series C_nH_{2n+2} is colorless and saturated throughout. So also is the C_nH_{2n} series so far as known, whether in unsaturated olefine (chain) or napthene (cyclic arrangement. The C_nH_n series (acetylene—benzene—retene) is also colorless.

The near carbons, lying in the field between C_nH_n and C_n must some of them be colored, approaching blackness as the carbon ratio increases. The degree of double and triple bonding does not however increase in any regular manner with the carbon

ratio, neither does the acidity or basicity of the hydrocarbons. Highly active silica is able to break the bonds even of the paraffins. The filtering action is much gentler, in the nature of anchoring polar molecules over a polar surface. Polarity is doubtless related to dissymmetry of structure but between this and carbon ratio (and color) there is no relation known at present.

PETROLEUM, SILICA AND WATER

Both water and petroleum are strongly adsorbed by silica. Fresh water is more powerfully adsorbed on clean silica than is fresh crude oil. If a drop of oil and a drop of water be placed between two glass plates, the water will quickly drive out the oil if the supply is maintained but even an excess of oil cannot be made to drive out the water. Crushed oil sand, saturated with oil, is readily freed completely from oil by a jet of fresh water.

On the other hand, sand wet with water will adhere to oil. Clean sand grains will adhere to an oil-water surface on the *water* side but not on the oil side. Coal grains and sand grains coated with tar or an oil-silica compound will stick on the *oil* side of such an interface but not on the water side. An instructive experiment is to place a thick layer of oil on water in a glass dish then drop in a few grain of sand. These, after falling through the oil, are quickly cleared of the oil by the water and stick to the under side of the oil on the water ceiling.

My explanation of this phenomenon [3] is that silica wet by water attracts the H^+ ions from the water to its surface, thereby forming a superficial coating of siloxyl radicles SiOOH which have a free bond ready to attach to the weak bases of the oil. Even powerful oil solvents are unable to dissolve or break down this coating. A water solution of a salt of a strong base and weak acid such as sodium carbonate however at once frees the oil from the silica as would be expected. If washing soda be added to the water in the experiment just mentioned, the sand will drop freely through the oil-water interface to the bottom of the vessel. The strength of the free bond on SiOOH (toward oil) is roughly

[3] J. Ind. and Eng. Chem., Oct., 1925.

equal to the weight of a million molecules of silica in water or about 10^{-16} dyne.

APPLICATION.

In the practical problem of driving petroleum from oil sand, the same water and oil must remain in contact for many months, since there can be but slight convection in the narrow pores. By the introduction of a liberal charge of washing soda into each well at the start of the water drive, the oil is freed from the sand and prevented from thickening up as described above. Numerous and varied laboratory experiments all indicate that the theory outlined in the preceding paragraph is correct and that a high percentage of oil recovery may be looked for.

Geochemically, silica and most silicates may be looked upon as (1) catalysts in aiding the production and maintenance of equilibrium between the various components of petroleum and (2) as filters for restraining the movement of components of high carbon ratio. If water or water solutions be present, considerable hydrolysis of the petroleum may be looked for and if there be movement, an accumulation of asphaltic material in the sand. The presence of metal salts in petroleum ash is not surprising since silica and silicates have been shown to combine directly with petroleum.

U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.

OCCURRENCES OF THE PLATINUM METALS IN SOUTH AFRICA.

PERCY A. WAGNER.

PART II.

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PLATINUM ASSOCIATED WITH MAGMATIC NICKEL-COPPER-IRON SULPHIDES.

The Potgietersrust Fields.

What are undoubtedly the most important platinum deposits so far discovered in South Africa are situated in the portion of the norite zone of the Bushveld Complex trending north-northwestward from Potgietersrust; the Potgietersrust fields having of late completely overshadowed those of the Lydenburg District. The great norite sheet is here much thinner than elsewhere and,

as already stated, cuts diagonally downward across the rocks of the Transvaal System, being floored by progressively lower sedimentary horizons until it rests directly on the Old granite. It is also evident from the geological map of the area [29] that the norite was intruded partly below and partly above the rocks of the Transvaal System, much the greater part of the huge sheet lying above these rocks. In the process of intrusion, huge masses of quartzite, shale, and dolomite, were detached from the floor of the lopoliths and engulfed in the norite. The sedimentary rocks flooring the lopoliths and composing the xenoliths caught up in the norite have, as might have been expected, suffered profound alteration. This applies particularly to the dolomite which has been converted into lime-silicate rocks and into serpentines derived from the alteration of the forsterite and forsterite-grossularite-spinel rock.

Platinum Deposits.—The platinum deposits which occur on three horizons include both strictly magmatic and contact metasomatic deposits. They lie on, or some little distance above, the floor of the main portion of the lopolith, and there are also important deposits in the sedimentary floor itself.

The lowest deposits stratigraphically are situated on the crest and upper slopes of a conspicuous bush-clad hill in the central part of Tweefontein, No. 1033. Here promising platinum values have been obtained in vertical, steeply-dipping, and almost horizontal crush-zones in a thick bed of banded iron-stone (taconite) occurring at the base of the dolomite series. The mineralized zones appear to be connected with apophyses of ultra-basic rock, which no doubt at one time continued upward into the originally overlying norite zone. The platinum, as elsewhere on the Potgietersrust field, is associated with nickel and copper. Analyses show up to 4.86% copper, 2.65% of nickel, and 10 dwts. of platinum per ton over fairly considerable widths.

On the southern slopes of the same hill there has been opened up in the lower part of the norite zone another important platinum horizon which has so far been traced for a distance of 1,700

[29] Sheet 7 (Potgietersrust), Transvaal, by E. T. Mellor and A. L. Hall.

feet. The ore-bearer is a thick layer of rather fine-grained pyroxenitic diallage-norite which is frequently seen to merge into coarse-grained bronzitite and felspathic bronzitite. The norite and associated pyroxenite enclosed big xenoliths of much-folded banded iron stone and quartzitic shale and are also seen to vein these rocks. The ore horizon thus evidently follows a xenolithic zone, immediately overlying the intrusive contact between the norite and the sedimentary rocks by which it is floored. The platinum-bearing rocks are mottled with copper and iron stains, and on the joints traversing them are found botryoidal crusts of an exquisite bright turquoise-blue tint. It is to be concluded from the presence of the secondary iron and copper minerals that below water level the ore will carry pyrrhotite, chalcopyrite, and pentlandite; analyses showing that nickel is also present. The mineralization, which is spread over a fairly considerable thickness of rock, is sporadic, sections showing fairly high platinum values alternating with others in which that metal appears to be present.

The highest assays so far recorded are from the Rhodesia Working where a section 40 feet wide averaged 7.5 dwts. per ton.

The Main Potgietersrust Platinum Horizon.

Lying probably about 200 feet vertically above the Tweefontein horizon, just dealt with, is the main platinum horizon of the Potgietersrust fields. This is probably the equivalent of the Merensky Horizon in the Lydenburg District. It has been traced at intervals in a general north-northwesterly direction for a distance of over 20 miles from the Potgietersrust Townlands to the farm Witrivier, No. 282. The nature and succession of the rocks that make up the horizon are variable, the only constant feature being the hanging-wall of rather coarse-grained anorthositic diallage-norite generally exhibiting a peculiar poikilitic texture.

The ore horizon consists, in the southern part of the area, that is, on the Potgietersrust Townlands and on the farms Turfspruit, No. 990 and Tweefontein, No. 1033, of a thick sheet of dark-

colored pseudoporphyritic diallage-norite of the Merensky Horizon type with segregations of coarse-grained bronzitite and felspathic bronzitite. The platinum values ranging from a fraction of a pennyweight to 3 pennyweights are confined to these pyroxenitic rocks except on the farm Tweefontein, No. 1033, where the pseudoporphyritic pyroxenitic norite itself carries platinum. North of Tweefontein on the farm Sandsloot, No. 276, the platinum horizon over considerable distances is made up entirely of coarse-grained felspathic bronzitite merging downward into coarse-grained hornblende-norite. Farther north on the farms Vaalkop, No. 256, and Zwartfontein, No. 121, these rocks are again overlain by barren pseudoporphyritic diallage-norite, and yet farther north they apparently disappear altogether; the ore-bearer on Drenthe, No. 982, and Witrivier, No. 282, being pseudoporphyritic diallage-norite.

By far the most important portion of the platinum belt is that situated on Sandsloot, No. 276, Vaalkop, No. 256, and Zwartfontein, No. 121. On these farms there have been opened up within the last six months deposits, of the first magnitude and importance, of some sections of which it may be prophesied with confidence that they will be highly profitable even if the price of platinum should fall to that of gold.

Sandsloot No. 276.—The main sector on this farm has a length of 2,200 feet and has been opened up at eleven points by means of shafts, cross-cuts, and trenches. The ore-body is best exposed in the No. 6 Working, where a shaft has been sunk to a depth of 37 feet—the underground water level—and a cross-cut and tunnels driven across and along the deposit at this depth. The outstanding feature of this sector of the ore horizon is the great thickness of the platinum-bearing rock. The width of the outcrop in the neighborhood of the No. 6 Working ranges from 175 to 180 feet, which, if the dip of the hanging-wall, namely 55°, can be taken as a measure of that of the whole ore body would give the latter a thickness of from 143 to 146 feet. The hanging wall is formed by the rather coarse-grained anorthosite-

norite previously referred to and the foot-wall by a fine grained anorthositic norite.

The uppermost 50 feet of the ore body, measured horizontally, are occupied by lustrous coarse-grained hypidiomorphic granular felspathic bronzitite, containing a good deal of dark-brown hornblende, which merges downward into coarse-grained hornblende-diallage-norite.[30] Above water-level these rocks show green copper and brown iron stains, while below the zone of weathering they are uniformly spotted with small sulphide specks. The felspathic bronzitite is very variable as to grain and composition. It is composed predominantly of polysynthetically twinned clino-bronzite which, according to its optical properties, must contain in the neighborhood of 7 per cent. of FeO. Some mineralogists would thus prefer to call it clino-enstatite.

The sulphide specks were again found by etching polished sections to consist of pyrrhotite, pentlandite, and chalcopyrite. The pentlandite occurs for the most part in thin discontinuous shells enveloping irregularly rounded grains of pyrrhotite.

The sampling of the No. 6 and adjacent workings proves that the best platinum values are contained in the upper 50 feet of the ore body, or in other words, in the felspathic bronzitite. The hornblende-diallage-norite carries lower values which dwindle to mere traces as the footwall of the ore body is approached. The results of the sampling of the main cross-cut of No. 6 Working by the engineers of the Potgietersrust Platinum, Limited, may be summarized as follows:

Section Sampled.	Average Platinum Content. (Dwts. per short ton.)
Uppermost 50 ft. (measured horizontally)	3.45
50–100 ft. (measured horizontally)	2.64
Upper 100 feet (measured horizontally)	3.05
100 ft. to 160 feet (measured horizontally)	3 to .1

It should be stated that there is no difference between the plati-

[30] A complete analysis of a specimen of sulphidic hornblende-diallage-norite from a point 120 feet—measured horizontally—from the hanging wall is given in column V. of Table III. This particular specimen was chosen because it happened at the time to be the best-preserved material available.

num content of the oxidized and sulphide ore. The shaft was also carefully sampled and to a depth of 37 feet returned an average of 4.6 dwts. per ton.

The workings immediately north and south of the No. 6 Working show practically the same section, the dip of the contact between the ore-body and the hanging-wall being here also 55° In the No. 4 Working the uppermost 100 feet of the ore-body measured horizontally averaged 3.1 dwts. of platinum.

The Vaalhoek-Zwartfontein Sector.—In this sector the dip is much lower than in the Sandsloot sector, ranging from 20 to 25°. The ore-bearing felspathic bronzitite is everywhere separated from the hanging-wall anorthosite-norite by a fairly considerable thickness of barren pseudoporphyritic diallage-norite and rests on a footwall of altered dolomitic rocks which also carry notable amounts of platinum. The lower part of the deposit on Vaalhoek, in particular, affords an admirable illustration of a contact metasomatic platinum deposit, the ore horizon here including a considerable thickness of altered sedimentary rocks.

Trench No. 1, Vaalhoek.—The section exposed in trench No. 1 Vaalhoek, is shown in Fig. 4. The pseudoporphyritic diallage norite separating the ore from the hanging-wall anorthosite has a thickness of about 80 feet. The ore-bearing felspathic bronzitite is a coarse-grained (2–15 mm.) rock composed mainly of clino-bronzitite with a slightly higher refractive index than that of the Sandsloot ore. It will be noted from the section that followed upward the felspathic bronzitite passes abruptly into the overlying pseudoporphyritic diallage-norite. This shows copper and iron stains near its contact with the felspathic bronzitite, and carries platinum. The platinum values, however, give out within a short distance of the contact.

The footwall section of the deposit is, however, of far greater interest than the hanging-wall section, alike from a strictly geological and from an economic point of view. The platinum-bearing bronzitite, as previously stated, rests on metamorphic rocks resulting from the alteration of dolomite. These include diopside-grossularite rock, granular malacolite rock, diopside-gros-

sularite-forsterite-calcite rock, and serpentines derived from forsterite-magnetite rock.

Careful sampling has proved that these rocks are fairly rich in platinum for a distance of over 20 feet measured horizontally from the bronzitite contact. The exact distance to which the

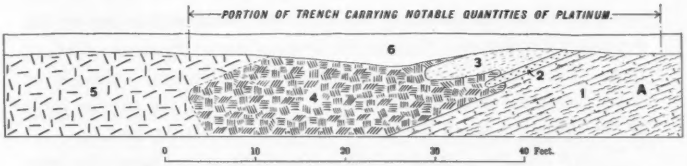

FIG. 4. Section across composite magmatic-contact metasomatic platinum deposit exposed in No. 1 Trench. Vaalkop, No. 256, Potgietersrust District. 1. Alternations of dolomite-serpentine and calc-silicate hornfels. 2. Granular malacolite rock. 3. Diopside-grossularite rock (1–3 all platinum-bearing). 4. Coarse-grained platinum-bearing felspathic bronzitite with copper and iron stains. 5. Pseudoporphyritic diallage-norite, platinum-bearing near its contact with 4. 6. Surface soil.

platinum impregnation extends has, as a matter of fact, not yet been determined. The platinum here is also associated with sulphides, present in some specimens in isolated specks up to 2 mm. across. Pyrrhotite and chalcopyrite are clearly recognizable and pentlandite is probably also present. The platinum and sulphides were evidently introduced into dolomite rendered porous by the expulsion of carbon dioxide by vaporous solutions emanating from the norite magma.

The platinum content of the felspathic bronzitite ranges from 2 dwts. to 21.7 dwts. per ton. A sample over 4 ft. taken by the writer in the hanging-wall of the deposit gave 4.1 dwts. of platinum, and another taken by Mr. W. O. C. Ross, Deputy Inspector of Mines, in the floor of the trench over a distance of 12 feet returned 12 dwts. of platinum. Within the section hitherto sampled the altered dolomitic rocks forming the footwall of the deposit have returned assays of from 4 to 10 dwts. of platinum per ton. A sample, over a thickness of 5 feet, taken by the

writer, at *A* in Fig. 4, near the eastern end of the trench, showed 4.8 dwts. of platinum per ton.

According to the assay plans prepared by the Engineers of the Potgietersrust Platinums, Ltd., the deposit as a whole, including felspathic bronzitite, ore-bearing diallage-norite, and the impregnated dolomitic footwall, averages 7.07 dwts. over a distance measured horizontally of 45 feet. Taking the dip of the deposit at 22 degrees, this would be equal to a thickness of 16.75 feet. The trench actually carries notable platinum values over a distance measured horizontally of 53 feet, and the precise limit of the deposit toward the east remains to be determined.

Trench No. 1—Zwartfontein.—Excellent values have also been obtained in Trench No. 1 on Zwartfontein No. 121, situated 270 feet north of the Vaalkop boundary, and 386 feet from the No. 1 Trench on that farm. Here again the ore body is of a composite nature, being made up of the lower part of a tabular body of coarse-grained felspathic bronzitite, a green serpentine rock of uncertain origin underlying the bronzitite and an as yet unknown thickness of dolomite serpentines underlying this serpentine rock.

The felspathic bronzitite has been proved to carry from 2 to 20.7 dwts of platinum per ton, and the serpentines up to 10 dwts. The average platinum content of the 28-foot composite section, above referred to, is 7.5 dwts. A sample over 5 feet taken by the writer in the felspathic bronzitite near its contact with the underlying serpentine assayed 6.35 dwts., another over 6 feet, taken by Mr. W. O. C. Ross, Deputy Inspector of Mines, in the same section of the ore-body, returned 9 dwts. per short ton.

The platinum-bearing bronzitite has been traced northward from the No. 1 trench on Zwartfontein for a distance of about 700 yards. The ore-body becomes thinner in this direction and also poorer in platinum. That it is also developed farther north in the central part of the farm is proved by the presence of alluvial platinum in the bed of the Zwartspruit which drains this portion of Zwartfontein.

It should be stated that satisfactory processes for the treatment of both the oxidized and the sulphidic ore have been

evolved. There is thus every likelihood of these great deposits and of the richer sections of the Merensky Horizon in the Lydenburg and Rustenburg Districts being worked on a huge scale, and becoming and remaining for very many years the principal source of the platinum metals.

Deposits of the Merensky Horizon Type Occurring Below and Above the Merensky Horizon in the Lydenburg District.

Deposits of the St. Edmonds Horizon.—Lying on a fairly well-defined horizon about 50 feet vertically below the Merensky Horizon in spotted anorthosite on the farm St. Edmonds, No. 220, Lydenburg District, are lenses of dark-colored platinum-bearing rock ranging in length up to 50 feet and in thickness up to 8 feet. The platinum bearer, which is very variable in character, is in part sulphidic pseudoporphyritic diallage-norite indistinguishable from that of the Merensky Horizon.

Some of the lenses have proved to be rich in platinum, carrying from 5 to 14.8 dwts. of that metal per ton. They are unfortunately of limited extent.

The same horizon has been picked up on Onverwacht, No. 330, and Driekop, No. 170.

Deposits of the Kalkfontein Horizon.—On the farm Kalkfontein, No. 22, adjoining Dwarsrivier, No. 86, lenses and stratiform bodies of platinum-bearing pseudoporphyritic diallage-norite are found on an horizon lying some 500 feet above the Merensky Horizon. The platinum bearer is, as a rule, indistinguishable from that of the Merensky Horizon. As in the latter the hanging-wall is formed of light-colored spotted anorthosite and the footwall of rock of the same character. The ore-bodies range in thickness from a foot to 7 feet. Samples taken by the writer returned from 10 grains to 6 dwts. per ton. The platinum, as seen in the pan, is in the form of minute square plates of tin-white color with brilliant metallic lustre. It looks quite different from the platinum of the Merensky Horizon. According to Dr. J. Moir it is unusually rich in palladium. This probably accounts for its white color.

Minsk Claims Type (Lydenburg District).

The deposits referred to are situated on Minsk's Claims on portion *A* of the huge farm Steelpoort Park, No. 246, situated south of the Steelpoort River in the Lydenburg District. They take the form of small irregular bodies of coarse-grained felspar-rich sulphidic diallage-norite, enclosed in medium grained spotted norite. They lie a short distance below one of the great stratiform segregations of titaniferous magnetite that are so characteristic a feature of the upper part of the norite zone.

A sample over a thickness of 42 inches in one of the workings assayed 5.5 dwts. of platinum per ton.

Steelpoort Park Type.

Deposits of this type occur in no fewer than five horizons in the upper part of the norite zone on portions *C* and *F* of the farm Steelpoort Park, No. 246. The ore-bearer, as already stated, is a medium-grained spotted felspar-rich norite uniformly interspersed with small sulphide specks. It is merely a sulphidic phase of the medium-grained spotted norite of which there is such an enormous development in the upper part of the norite zone.

The outstanding feature of the ore, in comparison with all the platinum-bearing rocks hitherto described, is its richness in soda-lime felspar. This is clearly brought out by the analysis given in Table III. It was to be expected from the position of the ore-bodies so high up in the norite lopolith, which, as the writer has shown elsewhere,[31] is stratified according to density.

The deposits are stratiform and persistent. They range in thickness from 12 inches to 3 feet. The average thickness on portion F of the farm,[32] where there are four distinct horizons within a vertical range of about 150 feet, is 18 inches. The ore-layers conform to the general pseudostratification of the rocks of the norite zone, the average dip being about 15 degrees.

[31] Memoir No. 21, Geol. Surv. Union of South Africa, pp. 78–79.

[32] The deposits on Portion F. of Steelpoort Park have been specially studied by Dr. E. Reuning, to whom the writer is indebted for much of the information given below.

The bodies of sulphidic norite are invariably overlain by layers of spotted anorthosite, which also sometimes carries sulphides and platinum. In places they are both underlain and overlain by spotted anorthosite. The platinum content of the sulphidic norite ranges from 0.4 to 2.5 dwts. per ton. The deposits do not appear to have any great economic significance.

Occurrences in Acid Differentiates of the Norite Magma.

Under this heading brief reference may be made to a number of platinum occurrences in the Lydenburg and Middelburg districts. They are of great scientific interest but of no economic importance.

Maandagshoek No. 148, Lydenburg District.—Lying 200 feet vertically above the Merensky Horizon on this farm is a lens of hornblende-rich pegmatitic rock about 60 yards long. It is composed of large crystals of lustrous brownish-black hornblende and yellowish-brown diallage lying in a matrix of quartz and white felspar. The hornblende-rich pegmatite is spotted with small sulphide specks and carries from a trace to 1.8 dwts. of platinum per ton.

A similar body of hornblende-bearing pegmatitic rock is exposed on the eastern slopes of the Lulu Mountains on the farm Garatouw No. 467.

Lagersdrift No. 82, Middelburg District.—On this farm small amounts of platinum have been found in a vein of a granitic rock composed of quartz, felspar, and biotite, which intersects norite and pyroxenite enclosing seams of chromite. The granitic rock is evidently an extreme differentiate of the norite magma like the pegmatitic veins recorded by the writer in the area containing the Vlakfontein nickel deposits.[33]

There is a similar occurrence on the farm Sterkfontein, No. 221, in the southern part of the Lydenburg District.

OCCURRENCES IN THE GREAT DIKE OF SOUTHERN RHODESIA.

The Great Dike is a remarkable intrusion, over 300 miles long and from 3 to 4 miles wide, extending in a north-northeasterly

[33] Cf. Mem. No. 21, Geol. Surv. Union of S. Africa, pp. 69–70.

TABLE III.

ANALYSES OF PLATINUM-BEARING ROCKS OF BUSHVELD IGNEOUS COMPLEX.

	I.	II.	III.	IV.	V.	VI.
SiO_2	34.25	5.00	55.30	51.50	48.70	47.70
TiO_2	0.05	——	0.10	0.20	0.15	0.10
Al_2O_3	1.45	13.85	2.20	5.40	8.35	21,80
Cr_2O_3	0.10	44.25	——	——	0.10	0.10
Fe_2O_3	2.90	0.50	0.45	2.40	0.95	2.05
FeO	35.55	26.20	10.05	11.00	6.25	6.00
MnO	0.40	n.d.	0.15	0.15	0.15	0.10
NiO	trace	trace	0.20	trace	0.39	0.39
CuO	——	——	——	trace	0.18	0.38
MgO	22.00	9.40	20.80	21.95	13.50	6.65
CaO	2.35	0.15	1.80	5.40	17.20	10.95
K_2O	nil	——	trace	trace	0.80	trace
Na_2O	0.20	trace	0.30	0.90	0.95	2.50
P_2O_5	0.05	n.d.	0.20	0.10	0.10	0.10
CO_2	trace	——		nil	0.20	0.05
S	——	——	——	——	1.05	1.35
H_2O-	——	——	0.10	0.45	0.20	trace
H_2O+	0.55	0.15	nil	0.40	2.50	1.35
Total	99.85	99.50	100.65	99.85	101.72	101.57
Less Oxygen equivalent to Sulphur	——	——	——	——	0.55	.58
Total	99.85	99.50	100.65	99.85	101.17	100.99
Platinum (Dwts. per Short Ton)	33.80	n.d.	nil	2.0	1.90	n.d.
(Per Cent.)	0.0057			0.00034	0.00032	
(Highest Platinum Values so far obtained from type of Rock analysed. Dwts. per Short Ton)	137.80	12.0		17.00	6.20	2.50
Specific Gravity	3.752	4.38	3.34	3.20	3.08	2.98
Analyst	H. G. Weall	H. G. Weall	H. G. Weall	H. G. Weall	H. G. Weall	H. G. Weall
Symbol	V.1.5.1.3.	V.5.1.1.2.	V.1.1.1.2.	IV.1.1.1.2.	IV.1.2.3.1–2.	II.5.4.4–5.

I. Hortonolite-Dunite, Onverwacht, No. 330, Lydenburg District, Transvaal.
II. Chromitite, Kroondal, No. 177, Rustenburg District, Transvaal.
III. Bronzitite, Vlakfontein, No. 902, Rustenburg District, Transvaal. This rock does not actually carry platinum, but is the country rock of the Vlakfontein Nickel Deposits.
IV. Oxidized pseudo-porphyritic pyroxenitic diallage-norite of the Merensky Platinum Horizon, Maandagshoek, No. 148, Lydenburg District.
V. Coarse-grained sulphidic hornblende-diallage-norite of the Main Potgietersrust Platinum Horizon, Sandsloot, No. 276, Potgietersrust District, Transvaal.
VI. Sulphidic felspar-rich spotted platinum-bearing norite. Steelpoort Park, No. 246, Lydenburg District, Transvaal.

direction almost right across Southern Rhodesia from the southern part of the Belingwe District to the extreme northern part of the Lomagundi District.[34] It is composed of norites, pyroxenite, peridotites, and serpentine derived from the last. The general similarity of these rocks to those of the norite zone of the Bushveld Complex renders it highly probable that the magma that gave rise to the Great Dike was derived from the same source and intruded at the same time as that from which the rocks of the norite zone of the Bushveld Complex crystallized.[35]

Some years ago a good deal of prospecting for platinum was done on the Great Dike. The results were disappointing though small amounts of the metal were found, according to the late A. E. V. Zealley,[36] six miles northeast of Indiva Siding in the Gwelo District, in a body of serpentinized dunite forming part of the big intrusion. A sample of concentrate from an unstated amount of the dunite was forwarded to the Imperial Institute, London, and was found on assay to contain platinum to the amount of 1 dwt. 20 grains per ton.

Within the past six months as a result of the platinum discoveries in the Transvaal, prospecting operations have been taken up with renewed vigor and what are said to be promising discoveries have been made in three widely separated areas, namely, in the Umvukwes to the northwest of Salisbury, near Makwiro west-southwest of Salisbury and in the Belingwe District.

Samples from Cullinan's claims in the Umvukwes near Lydiat Station northwest of Salisbury, were found to be similar to the rather fine-grained phase of the Merensky Horizon ore which is developed in places, except that pseudophenocrysts of diallage are here rare and small; none that the writer saw exceeded 1 centimeter across. The ore shows the usual copper and iron stains and is said to carry an average of 3 dwts. of platinum per ton.

V. Coarse-grained sulphidic hornblende-diallage-norite of the Main Potgietersrust Platinum Horizon, Sandaloot, No. 276, Potgietersrust District, Transvaal.
VI. Sulphidic felspar-rich spotted platinum-bearing norite. Steelpoort Park, No. 246, Lydenburg District, Transvaal.

[34] Cf. Maufe, H. B., "An Outline of the Geology of Southern Rhodesia," Short Report No. 17, S. Rhod. Geol. Surv.; also Zealley, A. E. V., *Trans. Roy. Soc. S. Africa*, 1915, pp. 1–24.

[35] Cf. Wagner, P. A., Memoir No. 21 Geol. Surv. Union of S. Africa, p. 89; and Zealley, A. E. V., *loc. cit.*

[36] Short Report No. 3, S. Rhodesia Geol. Surv., March, 1918.

OCCURRENCES IN THE GRANITE OF THE CAPE PROVINCE.

Some years ago Col. J. G. Rose, a careful and accomplished chemist, while in charge of the assay department of the Government Chemical Laboratory, Cape Town, examined a large number of rocks from different parts of the Cape Province for platinum. As a result of his investigations he came to the conclusion that platinum is fairly generally distributed in minute traces through the igneous rocks of that province. Among the rocks tested were different types of granite, dolerites from the Karroo and Graaff Reinet, and gabbro-norites of the Transkei. In no case did the quantity amount to more than a grain or two per ton. Recently he has again taken up these investigations and has been able to confirm the conclusions previously reached.[37] As a matter of general interest it may be recorded that special tests were made with blank charges to test the purity of the reagents used. Col. Rose found that the "pure" borax of commerce which is fused in platinum crucibles is not infrequently contaminated with platinum.

OCCURRENCES IN THE DIAMOND-BEARING CONGLOMERATES AND GRAVELS OF THE SOMABULA FIELDS.

The diamond-bearing conglomerates and gravels of the Somabula Fields near Gwelo, Southern Rhodesia, have been proved to contain small amounts of the platinum metals. A sample of the heaviest fine concentrate obtained in the washing for diamonds was tested at the Imperial Institute, London, and found to contain: "Platinum, 3 oz. 12 dwt. per ton of concentrate, osmiridium, 7 oz. 0 dwt. per ton of concentrate." Palladium was probably present, but the amount was too small to be definitely identified.[38]

The Somabula conglomerates have been proved to be of Upper Karroo age (Triassic). They contain rolled pebbles of fine-grained chromitite which, as the writer originally suggested,[39]

[37] Personal communication to the writer.

[38] Cf. Short Report No. 5, Southern Rhodesia Geol. Surv.

[39] "The Diamond Fields of Southern Africa," p. 287.

probably have their source in the Great Dike. It is very likely, therefore, that the platinum metals present were also derived from that remarkable intrusion. This view receives support from the fact that Zealley also noted in the conglomerate and gravels pebbles of silicified serpentine derived from the Great Dike.[40]

OCCURRENCES IN KARROO DOLERITE AND IN ROCKS ALLIED TO KARROO DOLERITE.

The most important deposits under this head are the magmatic nickel-copper occurrences of Insizwa and Tabankulu in Griqualand (East), Cape Province, which are well known among geologists through the writings of Rose,[41] du Toit[42] and Goodchild.[43]

The deposits occur near the lower contacts of great basin-shaped masses of gabbro-norite—a special phase of the well-known Karroo dolerite—which have been shown to be remnants of a vast sill intrusive in the lower division of the Beaufort Series of the Karroo System. The lower surface of the sill was evidently of an undulating nature. The existing occurrences represent the parts filling the hollows, the intervening dome-like connections having been removed by denudation. The individual gabbro masses show gravity stratification. They range in composition from gabbro with interstitial micropegmatite at the top through olivine gabbro and olivine norite to picrite at the bottom. The lowest layer of all is gabbro, evidently a chilled contact phase of the parent magma. The nickel-copper sulphides are associated with the picrite. In the Insizwa deposit both disseminated sulphide ore and massive sulphide ore are present; the former occurring as a big sheet-like body of rather low-grade

[40] Short Report No. 5, Southern Rhodesia Geological Survey.

[41] Cf. Rose, J. G., *S. A. Jour. Sci.*, Vol. VII., pp. 129–131. Cape Town, 1911.

[42] Du Toit, A. L., Geol. Surv. Union of S. Africa, Annual Rept. for 1912 and 1913.

Du Toit, A. L., Ann. Rept. Geol. Comm. Cape of Good Hope for 1910–1911.

Du Toit, A. L., "The Geology of the Transkei. An Explanation of Sheet 27 (Cape)," Geol. Surv. Union of S. Africa, pp. 18–27.

[43] Goodchild, W. H., "The Economic Geology of the Insizwa Range," *Trans. I. M. M.*, Bulletin 147, London, 1916.

ore; the latter in veins, stringers, and fairly extensive bodies of tabular shape.

Du Toit estimates that the disseminated sulphide ore making up the bulk of the deposit averages from 2.5 to 3.5% of nickel plus copper, these metals being present in approximately equal proportions. The ore-minerals are pyrrhotite, chalmersite,[44] pentlandite, and chalcopyrite with smaller amounts of bornite, niccolite, and zincblende. That small amounts of the platinum metals are present was first established by J. G. Rose. Assays of several ounces to the ton have been recorded, but the average appears to be between ½ dwt. and 1 dwt. per ton. It was always assumed that platinum predominated and that it was accompanied by subordinate amounts of palladium. Recent tests by a world-renowned ore-extraction firm on a bulk sample of the ore proved, however, that in this particular sample only palladium was present.

There is a consensus of opinion among geologists who have visited the occurrence that the mineralized zone on which most of the exploratory work has been done at Insizwa is the eastern edge of a large concealed lens-shaped mass of ore. To test this hypothesis, an inclined tunnel was driven into the mountain side some years ago, along the lower contact of the ore-body which dips inwards at about 22°. Unfortunately the available funds were exhausted before any definite conclusion could be reached. At present the deposit is not being developed, but it was announced recently that further capital had been raised for carrying out this exploratory work.

In the neighboring gabbro-norite mass of Tabankulu smaller bodies of the same type of ore have been located.

Apropos of the foregoing it is of interest to recall that Col. J. G. Rose, in his investigations, previously referred to, on the platinum content of the igneous rocks of the Cape Province, found that minute traces of platinum metals are fairly generally distributed through the dolerites of the Karroo.

[44] Cf. Pinger, A. W. Quoted by Wandke, A., and Hoffman, R., ECON. GEOL., 1924, p. 202.

Appreciable amounts of platinum are said to have been found many years ago in a hybrid acidified Karroo dolerite at Bekkers Kloof near Cradock, Cape Province. So far as the writer is aware the statement has never been confirmed.

During 1921 great interest was aroused by the news of important platinum discoveries in the neighborhood of the village of Cala situated 80 miles north of Queenstown in the Transkei division of the Cape Province. The metal was alleged to occur in a great dike of decomposed Karroo dolerite intrusive in the Stormberg beds, and in eluvial and alluvial deposits derived from this source.

Fairly high assays were recorded both from the dolerite and from the detrital deposits. Subsequent investigations by independent engineers failed, however, to substantiate the claims made in respect of these deposits, and nothing has been heard of them since. There are thus strong reasons for doubting the authenticity of the original finds. The same applies to the alleged discoveries of platinum made some 20 years ago near Grahamstown in ochreous shale belonging to the Witteberg Series.

OCCURRENCE IN KIMBERLITE.

The late Victor Hartog[45] succeeded some years before his death in establishing the presence of small amounts of the platinum metals in the kimberlite of all the more important South African diamond pipes, namely, Kimberley, De Beers, Bultfontein, Du Toit's Pan, Wesselton, Jagersfontein, and Premier.

The platinum metals were found in every instance to be associated with the chromite of the kimberlite. In addition to platinum, iridium or osmium, or, as is more probable, both these metals are present.

The kimberlite pipes, it should be stated, are either of late Cretaceous or early Tertiary age.

[45] Cf. Wagner, P. A., "The Diamond Fields of Southern Africa," p. 77.

THE PLATINUM DEPOSITS OF THE WATERBERG DISTRICT.[46]

These are by far the most important platinum deposits in lode form ever discovered; the rather unique conditions in which the metal is here found and the phenomenal richness of the lodes in places having invested them with a peculiar interest.

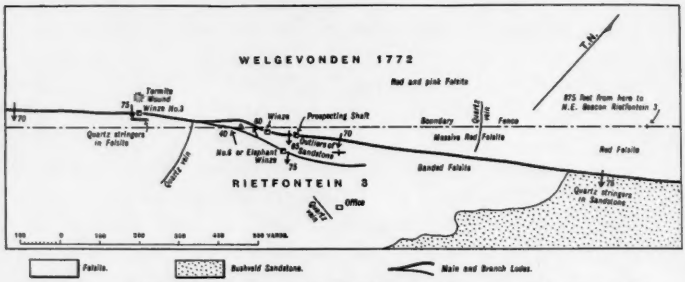

FIG. 5. Plan of platinum lodes being opened up on the Farms Rietfontein, No. 3, and Welgevonden, No. 1772, by Transvaal Platinum, Ltd.

They are situated in hilly country in the Central Transvaal some 8 miles west-northwest of Naboomspruit station on the Pretoria-Pietersburg railway. The deposits take the form of brecciated quartz lodes occupying faults of post-Karroo age in felsite and felsite tuff belonging to the Bushveld Igneous Complex. A number of lodes have been discovered in a strip of country some 18 miles in length. They have a prevalent E.N.E.–W.S.W. or N.E.–S.W. trend. Small local concentrations of platinum have been found in most of the lodes, but workable bodies of ore have so far only been opened up in the so-called Main and Branch lodes on Rietfontein, No. 3, and Welgevonden, No. 1772.[47] These are being exploited by the Transvaal Platinum, Ltd.

The Main Lode can be traced at the surface without a break

[46] Cf. Wagner, P. A., and Trevor, T. G., "Platinum in the Waterberg," S. A. Jour. Industries, December, 1923.

[47] Small amounts of platinum have also been found in similar lodes on the farm Elandsfontein, No. 1782, situated 38 miles southwest of these occurrences.

for 2½ miles. It ranges in thickness from 6 feet to 60 feet, and dips to the southeast at from 60° to 75°. Near the boundary fence of the farms Rietfontein, No. 3, and Welgevonden, No. 1772, it sends off a branch into its hanging wall. This can be followed for a distance of 1,240 feet. It varies in thickness from 4 feet to 30 feet. It is from this Branch Lode that some of the richest ore found has been obtained.

The Main and Branch lodes present much the same features and are what are known as composite lodes. Their filling varies greatly in character. In places it consists of a number of more or less closely spaced quartz stringers separated by strips or tabular masses of felsite, sometimes of considerable thickness. The quartz stringers everywhere exhibit comb structure being made up of slender crystals of opaque white quartz arranged at right angles to the walls. The combs are invariably banded or crustified as a result of breaks in the inward growth of the quartz crystals which appear as a rule to have coincided with the deposition of thin layers of other minerals.

More commonly the lode matter is conspicuously brecciated, angular fragments of pink and red felsite and of earlier-formed quartz combs generally accompanied by specularite lying in a matrix of later white quartz interspersed with vugs lined with quartz crystals. A true cockade structure is in places developed. Even a casual examination of the lode matter makes it apparent that there must have been several periods of brecciation and quartz deposition. At least four such periods can be distinguished, and at an even later stage, after still further brecciation, greenish, yellow, and brown chalcedony was deposited in irregular veins and crusts.

The mineralogy of the deposits is comparatively simple. Apart from the quartz and chalcedony there are present specularite, secondary iron oxide (mainly hematite) evidently derived from the oxidation of pyrite, pale-green sericite, deep leek-green chromiferous chlorite, kaolin, and pyrolusite. The last was noted only in one specimen where it forms botryoidal crusts composed of slender fibers lining a vug. The chromiferous chlorite, evi-

dently a secondary mineral, is fairly abundant but no mineral containing either nickel or copper is present.

Platinum is rarely visible except in specimens of the very rich ore in which small gray or grayish-yellow metallic specks can be made out with the aid of a lens. On polished surfaces of such ore the platinum shows up much better in bright silvery white specks. The platinum is present in two distinct generations. That of the earlier generation occurs in irregular forms with ragged edges, also in globular and reniform grains. The grains range in diameter from .04 to .6 mm. In some of the concentrically banded quartz combs the metal occurs in peculiar club-shaped and pear-shaped forms as a consequence of having been deposited between radially disposed quartz crystals. The platinum of this generation is, as a rule, intimately intergrown with specularite, or imbedded in aggregates composed of crystals of that mineral. The platinum of the second generation forms minute microscopic grains imbedded in secondary iron oxide evidently derived from the oxidation of pyrite which was in some instances clearly moulded on the platinum of the earlier generation.

The platinum, as appears generally to be the case with lode platinum, is alloyed with palladium; containing from 7 to 45% of that metal. Iridium and other metals of the platinum group are present in traces only, but analyses prove that the platinum contains from 0.3 to 3% of gold. An interesting fact brought out by recent investigations is that there is a marked difference between the composition of the platinum of the Main and Branch lodes. The former never contains more than 8% of palladium, while the latter contains anything from 20 to 40% of that metal. This difference in composition is well brought out by the following analyses by F. W. Watson and R. A. Cooper kindly placed at the writer's disposal by Dr. E. T. Mellor. They are of platinum from the No. 3 or Termite Mound Winze on Welgevonden, No. 1772, and the No. 6 or Elephant Winze on Rietfontein, No. 3, which, as will be seen from Fig. 3, are only about 1,100 feet apart.

	Welgevonden	Rietfontein
Pt	91.9	59.9
Pd	7.0	37.1
Au	0.4	3.0
Totals	99.3	100.0

Etching tests[48] on polished sections of the rich ore prove that the platinum is conspicuously zonal in structure, being made up of alternating layers of palladium-rich and palladium-poor platinum. The peculiar globular and reniform shapes of some of the platinum grains and their concentrically banded structure suggest the possibility of the platinum having been deposited from colloidal solution as a gel which only assumed a definite crystalline structure after deposition.

Distribution of the Platinum.—The distribution of the platinum in the lodes is extraordinarily erratic. The workable bodies of ore form irregular patches surrounded by barren lode matter. Such patches range up to 70 feet in length and up to 50 feet in vertical extent, but as a rule they are much smaller. Their horizontal dimensions are generally in excess of their vertical, so that it would not be correct to designate them ore-shoots. Within the limits of such patches specularite is a good indicator of high platinum values, the two minerals having evidently been deposited under the same physical conditions.

Some remarkably high assay values have been recorded. A picked specimen from the Elephant outcrop on Rietfontein No. 3 assayed 3,246 dwts. per short ton, equivalent to 0.55%. A grab sample from the No. 6 winze on Welgevonden returned no less than 3,345.5 dwts. (0.57%), and another sample from the No. 3 paddock, Welgevonden, 2,750 dwts. (0.47%). These are surely the highest platinum assays ever recorded. A 50-foot stretch on the outcrop of the Branch Lode averaged 1,019.5 dwts. over 35 inches, and a stretch of the same length on the Main Lode on Welgevonden, 107.5 dwts. over 20 inches. At a depth of 50 feet below the latter stretch a section of the lode 26

[48] Cf. Stanley, G. H., and Wagner, P. A., "Note on the Microstructure of Transvaal Platinum." *Jour. Chem. Met. Min. Soc. S. Africa*, March, 1925.

feet long averaged 270 dwts. over 60 inches. The highest assay so far recorded on the 100-foot level is 274 dwts. to the short ton.

The Main and Branch lodes have now been thoroughly prospected over a distance of 1,000 yards to depths ranging from 100 to 150 feet. It is estimated that platinum ore to the value of £500,000 is in sight, and high values are still being obtained at the lowest points reached. A treatment plant with a capacity of 1,000 tons per month is being erected. This should be complete and producing platinum early in 1926.

Genesis of the Deposits.—The genesis of the Waterberg deposits presents a fascinating problem. The nature of the lodes, and the crustified vuggy character of the lode filling, point to their formation under relatively light load near the surface. The abundance of specularite points, on the other hand, to the vapors and solutions that deposited the ore minerals having had a fairly high temperature. We have thus evidently to do with a high temperature deposit formed near the surface. It is probable that, as in the case of many tin deposits, for example, there was an early pneumatolytic stage during which quartz, platinum, specularite, and pyrite were deposited, and a later hydrothermal stage during which practically pure quartz and chalcedony were deposited from ascending heated waters. Hot springs still issuing in places along some of the faults may represent the final stage of the hydrothermal activity. The vapors and solutions evidently emanated from a body of igneous rock situated at no great depth, as it would otherwise be difficult to reconcile the high temperature character of the early mineralization with the formation of the deposits near the surface. As to the nature of the igneous rock, the predominance of silica in the deposits suggests that it must have been of a persilicic nature. The abundance of chromiferous chlorite, an unusual mineral, in quartz lodes suggests on the other hand a basic or ultrabasic magma. It is possible, therefore, that the persilicic vapors and solutions that formed the lodes may have been the reaction residuum left over in the crystallization of a basic or ultrabasic magma; and the

platinum metals extracted from this magma by "gas fluxing"[49] were concentrated in persilicic extract.[50]

The only igneous rocks of post-Karroo age hitherto identified on the plateau tract of South Africa are the kimberlites and the nepheline basalts and limburgites of the Limpopo valley.[51] The last, according to Rogers, contain amygdales of pure quartz up to 7 inches across. These siliceous secretions illustrate the separation of persilicic rock from an ultrabasic magma. There is no reason for assuming, however, that there is any genetic relation between the limburgites and these Waterberg deposits.

As to the nature of the vehicle by which the platinum was transported we are in complete ignorance. Chlorine or fluorine at once suggest themselves, but no mineral containing either of these elements is present. It is just possible that it may have been water vapor in which the platinum was in colloidal suspension in the form of some compound such as hexa-hydroxyplatinic acid, $PtH_2(OH)_6$; the shape and structure of many of the grains suggesting, as previously remarked, that the platinum was deposited as a gel. All this, however, is frankly speculative.

ELUVIAL AND ALLUVIAL DEPOSITS.

Eluvial Deposits of the Lydenburg District.—The platinum bearing dunites of the Lydenburg district have in proportion to

[49] Cf. Lindgren, W., ECON. GEOL., 1923, pp. 423–424; also cf. Wagner, P. A., ECON. GEOL., 1925, p. 283.

[50] Reference to the accompanying map (Fig. 1) will show that if the norite zone of the Bushveld Complex is continuous between the northernmost points at which it is exposed in the Rustenburg and Potgietersrust districts respectively, it must underlie the area containing the Waterberg platinum lodes. This suggests the possibility of the platinum contained in these lodes having been extracted from the rocks of the norite zone by magmatic vapors and solutions emanating from a totally different source. The fundamental difference in chemical composition between the platinum of the norite zone and that of the Waterberg lodes is, however, sufficient in itself to negative this hypothesis. To assume, as some writers have done, that the formation of the lodes is related to the intrusion of the Bushveld norite is to show a complete misunderstanding of the time relation between these two geological phenomena.

[51] Cf. Rogers, A. W., "Notes on the Northeastern Part of the Zoutpansberg District," *Trans. Geol. Soc. S. Africa*, 1925.

their size given rise to fairly considerable deposits of platiniferous eluvium and rubble. These take the form of irregular sheets of surface detritus and soil covering the slopes and flanks of the hills on which the dunite outcrops. The biggest deposits are on the farms Onverwacht, No. 330, Mooihoek, No. 147 and Driekop, No. 170. Platinum is present in well-shaped crystals and in irregular grains and nuggety forms. Some of the eluvium has been found to carry as much as 70 dwt. per ton, but the bulk of it only carries a few pennyweights. The exploitation of this material, which should prove highly profitable, is to be undertaken in the near future.

Alluvial Deposits of the Lydenburg District.—Though it might have been expected from the enormous amount of denudation that has taken place that extensive alluvial deposits would be found in connection with the Lydenburg platinum occurrences, this is not so. The only considerable deposits are those along the Steelpoort River. The largest of these is situated below the new Road Bridge near Fort Burger. It forms a terrace built up of some 20 feet of sandy overburden, overlying an unknown thickness of gravel composed almost entirely of rocks belonging to the norite zone. This gravel has been proved to carry platinum and is at present being tested systematically. There are similar deposits on the farms Leeuwvallei, No. 185, and Kennedy's Vale, No. 253, and a fairly big patch of high-level gravel has been located on the farm Sterkfontein, No. 187. Patches of platiniferous alluvium have also been found along some of the normally dry water courses traversing the area. These are probably of quite recent formation, but the terrace and high-level gravels probably date back to Tertiary time.

Alluvial Deposits in the Valley of the Olifants River.—Alluvial platinum, evidently derived from the denudation of the rocks of the norite zone of the Bushveld Complex, has also been found in the gravels of the Olifants River in the eastern and southern portions respectively of the Lydenburg and Leydsdorp districts. It is claimed of these alluvial deposits that they are of consider-

able extent and value, but no authentic information about them is as yet available.

Alluvial Deposits of the Potgietersrust District.—A promising stretch of platiniferous alluvium has been opened up on the Zwartspruit in the southern part of Zwartfontein, No. 121. It has a proved length of 600 yards and a width of 100 yards. The platinum is found beneath from 2.5 to 3 feet of sandy overburden in a layer of coarse grit carrying pebbles up to 2 inches across. In the pit where it is best exposed the platinum-bearing layer averages 6 inches in thickness and, judging by pannings, carries between 1.5 dwts. of platinum per ton.

The platinum is partly in the form of cubes up to 1 mm. across. These are little worn, but their faces like those of the platinum cubes found in the Sandsloot ore show peculiar pittings and depressions.

The Zwartspruit is tributary to the Magalakwin, along the course of which alluvial deposits should also be found.

Alluvial Deposits in the Rustenburg District.—Small nuggets and worn crystals of platinum, up to 1.5 mm. across, and smaller grains of that metal have been found in the gravels and sands of the Magato Spruit on the farms Doornspruit, No. 878, and Klein Doornspruit, No. 255, situated in the norite zone of the Bushveld Complex to the north-northwest of Rustenburg; also in the small water-course tributary to the Magato Spruit which crosses the farm Turffontein, No. 297. There do not appear to be any considerable accumulations of gravel on the farms named, but such exist along the Elands River into which the Magato Spruit discharges. These have not been tested so far.

The Alluvial Deposits of the Waterberg District.—Fairly extensive deposits of platiniferous alluvium have been located in the valley of the stream draining the area containing the platinum lodes on the farms Welgevonden, No. 1772, and Rietfontein, No. 3 in the Waterberg district. The biggest deposit underlies a terrace on the north side of the stream. It extends from Rietfontein, No. 1638, across Diamant, No. 2245, into Rietvalley, No. 1438. The deposit has been tested on the farm Diamant by

the Alluvial Platinums, Limited. Sections exposed in their workings show from 15 to 20 feet of clayey overburden overlying from 7 to 18 feet of gravel. The gravel carries small amounts of fine platinum, and efforts at recovering it have so far proved unsuccessful.

GENERAL GENETIC CONSIDERATIONS.

It will be evident from what has gone before that the metals of the platinum group are unusually abundant in South Africa. In no other part of the world, so far as the writer is aware, are they so widely distributed, and no other country certainly can show such concentrations in the mother rock. It is evident also that platinum-bearing rocks have been represented in practically all of the periods of igneous activity in the long geological history of the sub-continent, even going back to the earliest Archaean.

The widespread occurrence of the platinum metals is thus clearly due to some deeply underlying cause that has operated continuously throughout geological time. In endeavoring to seek this cause, it will be necessary first of all to consider briefly the probable structure of the outer part of the earth.

There is a fair consensus of opinion among geologists that this consists of concentric shells of rock of gradually increasing density. There is also very strong evidence to support the view of Daly [52] that the continental or *sial* crust and the ocean basins are underlain by a universal shell of basaltic composition. From what is known of the process of crystallization of basic igneous rocks there is every reason to suppose [53] that this shell merges downward into a shell of peridotite—the *sima* zone of Suess [54] which either underlies or, as appears more probable, includes the eclogite shell of Goldschmidt.[55]

[52] See "Igneous Rocks and their Origin," pp. 164–166; also Joly, J., "Radioactivity and the Earth's Crust," being the Halley Lecture delivered on 28th May, 1924, Oxford University Press, and other publications by the same author.

[53] Adams, L. H., *Jour. Wash. Acad. Sci.*, December 4, 1924.

[54] "The Face of the Earth," Volume IV., p. 544.

[55] "Der Stoffwechsel Der Erde," *Vid. Skrif. I. Mat.-Naturv. Klasse*, Kristiania, 1922, No. 11.

Most geologists are also in agreement with Suess' view [56] that the *sima* zone is the original home of the platinum metals found in the portion of the earth's crust accessible to our observation.

Granting that the hypotheses here briefly outlined are correct, then the unusual abundance of platinum metals in the igneous rocks of South Africa could easily be explained on the assumption that the portion of the *sima* zone underlying the sub-continent is abnormally rich in platinum. Even if this should be so it would still be necessary, however, to account for the linear arrangement of the principal deposits described in the preceding pages. Reference to Fig. 1 will show that despite their being so widely separated in age these are all confined to a more or less meridional belt lying between longitude E. 26° and longitude E. 30° 40′; while the occurrences of the Insizwa and Lydenburg areas and those of the Great Dike of Southern Rhodesia lie between longitude E. 29° 20′ and longitude E. 30° 40′.[57] It is clear that there is here a great *platinum belt* that cuts indiscriminately across the oldest and youngest geological formations, completely disregarding geological structures and structure lines in the more superficial parts of the earth's crust.

To J. E. Spurr we owe the conception of great *ore canals* of this nature, stable throughout geological time, along which the most important mineral deposits of the world are situated, and which pursue their way across continents regardless of rock formations and of the folding and faulting in them; their position being thus evidently determined by structural features in the portion of the earth's crust underlying that exposed to our view by denudation.[58] Spurr's idea is that when one of these ore canals taps a portion of a sub-crustal layer particularly rich, let us say, in copper, the igneous rocks along the line of the ore canal will be abnormally rich in copper, and so with silver and other metals.

Again accepting the correctness of this hypothesis we may conceive the presence below the eastern part of the South African

[56] *Loc. cit.*

[57] The position of longitude E. 30° as shown in Fig. 1 is not quite correct.

[58] "The Ore Magmas," Chapter XI.

Shield of a great platinum canal that, from the earliest geological times, facilitated the upward transference of the metals of the platinum group from an especially platinum-rich portion of the *sima* zone into the rocks forming the continental crust.[59]

It would appear, therefore, that the portion of the *sima* zone underlying the southern part of Africa is abnormally rich in the platinum metals, and that there exists beneath the eastern part of the South African Shield a great ore canal that throughout the geological ages has facilitated the upward transference of these metals. Further platinum discoveries are to be expected along the course of the canal.

ACKNOWLEDGMENTS.

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[59] Incidentally it may be remarked that, as the platinum belt includes the greater part of the remarkable Southeast African gold province responsible at the present time for over 55% of the world's annual production of that metal, and gold is not infrequently associated with platinum in the primary occurrences, the gold probably came up along the same canal as the platinum and along one paralleling it on the east.

THE BRITANNIA MINES, BRITISH COLUMBIA.*

STUART J. SCHOFIELD.

INTRODUCTION.

THE Britannia mines belong to the chalcopyrite deposits in schists and since the geological relationships here are clearer than in most deposits of similar characteristics, it is believed that the description will be of interest to economic as well as to structural geologists.

This mineralization is one of several which occur along the Pacific Coast and the description of the Beatson Copper mine, Alaska,[1] has thrown some light on these occurrences.

The Britannia mines are located about twenty miles north of Vancouver in the mountains of the Coast Range of British Columbia to the east of Howe Sound at an elevation of 2,000 feet above sea level. The individual mines from west to east along the shear zone are, Jane, Bluff, Fairview, Empress, and Victoria.

The total production of copper from the Britannia Mines since the beginning of operations in 1906 until 1924 inclusive has been 200,387,568 pounds.

The field work on which this paper is based was done when the writer was acting as consulting geologist for the Howe Sound Company.

THE MINERAL BELTS OF BRITISH COLUMBIA.

There are two main mineral belts in British Columbia[2] that are separated from each other by an elongated and curved massif of plutonic rocks, mainly granodiorite and quartz diorite which were intruded at the close of the Jurassic Period. This massif

* Presented before the Society of Economic Geologists, New York Meeting, May, 1925.

[1] Alan M. Bateman, ECON. GEOL., vol. 19, 1924, p. 338.

[2] S. J. Schofield, Geol. Surv. Can., Mem. 132, 1922, p. 63.

includes the Coast Range batholith of British Columbia and the majority of the batholiths occurring in the southern part of British Columbia.

The belt which follows along the Pacific Coast may be called the *Pacific mineral belt;* that along the eastern side of the same batholith, the *Interior mineral belt.* It will be remarked that the two belts differ in the mineralogical composition of their ore bodies. The ore deposits of the Pacific belt are sought mainly for their copper content; those of the Interior Belt for their gold, silver and lead content. It is only necessary to mention Anyox, Marble Bay, Quatsino Sound, Sunloch, and Britannia of the Pacific Belt and Salmon River, Premier Mine, Engineer Mine of Atlin, Bear River, Dolly Varden Mine of Alice Arm, Hazelton (excepting Rocher Deboule) and the deposits of Ootsa and Whitesail lakes to be convinced of the truth of the above statement. The Pacific and the Interior Belts of mineralization strike in a northwesterly direction parallel to the Pacific Coast but in the neighborhood of Vancouver, they turn eastward conforming in general with the batholiths of southern British Columbia. To avoid confusion it is suggested that the northerly belt be called the *Kootenay Mineral Belt* and the southern one the *Boundary Mineral Belt.* The metal content of the Pacific belt predominates also in its easterly extension the Boundary Belt and the same holds true of the eastern extension of the Interior Belt, the Kootenay belt. The two belts merge in the area located about the southern part of Kootenay Lake. The Boundary Belt includes Highland valley, Copper Mountain, Phoenix, Deadwood, Rossland and the Kootenay Belt embraces Ainsworth. East Kootenay (Sullivan, North Star, St. Eugene) Slocan, Lardeau, Revelstoke, Stump Lake, mineralized areas.

The Britannia ore deposits occur in the Pacific Mineral Belt and are characterized by copper bearing minerals.

GENERAL GEOLOGY.

The rocks in the vicinity of the Britannia mine form part of a large roof pendant composed of Jurassic volcanic, sedimentary,

and plutonic rocks which occurs along the southwest border of the Coast Range batholith of British Columbia.

The geological events of this region may be summarized as follows:

Tabular Statement of Geological Events.

Quaternary	Post Glacial	18. Deposition of river gravels. 17. Gradual uplift and erosion.
	Glacial	16. Erosion, Deposition of glacial drift.
Tertiary	Pliocene	15. Erosion and uplift.
	Miocene	14. Erosion.
	Oligocene	13. Erosion.
	Eocene	12. Uplift of peneplain—erosion.
Mesozoic	Cretaceous	11. Erosion, probable peneplanation.
	Jurassic	10. Intrusion of lamprophyr and aplite dikes. 9. Deposition of native sulphur and gypsum. 8. MAIN PERIOD OF MINERALIZATION. 7. Intrusion of diorite dikes. 6. Intrusion of Coast range batholith. 5. Orogenic movements and shearing, formation of chlorite schist from quartz diorite. 4. Intrusion of gabbro dikes. 3. Intrusion of quartz diorite (*Britannia sills*). 2. Deposition of slates (*Britannia formation*). 1. Accumulation of ash, slates, conglomerates, agglomerates and lava flows (*Goat Mt. formation*).

Goat Mountain Formation.—This formation is dominantly of volcanic origin. The lower part consists mainly of tuffs and agglomerates but contains at several horizons bands of slates and in one place a band of white quartzite, and conglomerate. The tuffs are massive fine grained black rocks which in many places show their banded character by differential weathering. The ag-

glomerates consist of angular pieces of volcanic rock sometimes amygdaloidal embedded in a fine grained matrix of tuff.

The upper part of the formation embraces chiefly volcanic rocks which may be flows. They are chiefly andesitic in composition and contain many bomb-like masses.

No ore bodies have been found in this formation.

The Britannia Formation.—The relationship of this formation to the above mentioned rocks is not quite certain but from the field evidence collected in this as well as in other areas in British Columbia, it is concluded that the Britannia formation overlies the Goat Mountain formation.

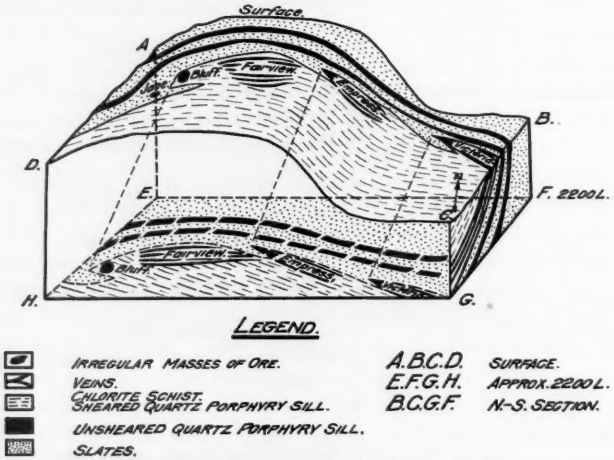

FIG. 1. Block diagram of Britannia Mines, B. C.

The Britannia formation consists almost entirely of black slates although in the neighborhood of the mineralized zone the slates are a light grayish-green color and are readily confused with the sericite schists. The bedding planes of the slates near the shear zone are almost obliterated by shearing. In general they strike N. 45° W. and dip 45 to 60 degrees to the south.

Included in the slates are bands of argillaceous quartzites which are exposed in the Jane mine and strata of chert which

occur with the slates along the " Incline " from Mineral creek to the Beach on Howe Sound.

The slates form the footwall of all the mines and form the hanging wall of the wedge like masses of orebearing schist which project into the slates. (Figs. 1 and 2.)

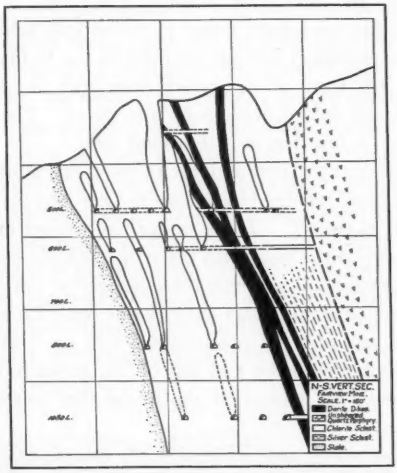

FIG. 2. N.–S. Vertical Section of Fairview Mine.

The argillaceous quartzite in the Jane mine usually carries the mineralization.

The Britannia Sills.—The Britannia sills are the most important rock masses in the Britannia mine since the chlorite schist derived from the shearing of these sills contains with one exception, all the commercial ore bodies.

The Britannia sills are composed mainly of quartz diorite porphyry which has more acid as well as more basic facies. The typical rock is light gray in color showing phenocrysts of quartz and andesine. The colored constituents, mica and hornblende, are small in amount. The name quartz porphyry is applied locally to this rock. The quartz diorite passes by gradation into

gneissic quartz diorite, into chlorite schist and in some places where the metamorphism was more intense into sericite schist.

The chlorite schist which is of light gray color mottled with masses of chlorite as large as one inch in length is commercially the most important rock in the region as all the ore bodies with one exception, the Jane Mine, occur in this rock.

No ore bodies have been found in the sericite schist.

The quartz diorite is intruded parallel to the bedding planes of the slates in the form of sills which have been intruded into the slates, tilted and folded along with the slates. These sills vary in width from a few feet to a thousand feet.

They strike N. 45° West and dip 45 to 60 degrees to the south. From the main sill, wedge-like masses project into the slates along the foot wall of the sill. These wedge-like projections plunge at an angle of 45° to the west with the strike and dip approximately parallel to the main sill. Hence these wedges of schist with their capping of impermeable slates gave rise to very favorable conditions for the deposition of ore bodies. The ore bodies conform in position with the strike and dip of the schist and plunge in conformity with the plunge of the wedge-like masses of schist (Fig. 1).

The sills in places are crowded with inclusions of quartzite and in some cases with masses of slates which have been baked to a dense black rock with conchoidal fracture. The presence of these inclusions shows conclusively that the quartz diorite is of intrusive origin.

Schists derived from quartz diorite contain ore bodies of commercial importance in other parts of British Columbia, namely at Anyox and the Premier mine and also the shape of the quartz diorite is in the nature of a laccolith at Anyox according to J. A. Bancroft and as a sill at the Premier mine.[3]

The Silica Rock.—The largest wedge of all, the Bluff, is filled with a mass of tough quartz which breaks with conchoidal fracture. Enclosed in this mass of silica are fragments of slate which have been highly silicified. All gradations exist from almost

[3] S. J. Schofield, Geol. Surv. Can., Mem. 132, 1922, p. 21.

pure silica to the green schist thus showing conclusively that the silica rock has been formed from the green schist by silicification. Ghost-like masses of chlorite can be seen in certain lights in the silica. The origin is substantiated by the structural relations of the wedge as well as from the fact that the other wedges of the Empress and Victoria mines do not show silicification to any extent, the wedge being composed of silicified chlorite schist.

The Coast Range Batholith.—The Coast Range batholith of Upper Jurassic Age borders the Pacific Coast of British Columbia from Vancouver to the Yukon, a distance of over 1,000 miles. Its average width is about 50 miles but in the neighborhood of Britannia mines it reaches 75 miles in width. In general it may be said that the central portion of the batholith[4] is made up of granodiorite becoming more basic and changing gradually into quartz diorite at the contacts with the intruded rocks. The basic phase is more pronounced and wider along the Pacific border than along the Eastern border where in fact the quartz diorite phase may be missing and the granodiorite occur in contact with the intruded rocks (Fig. 3).

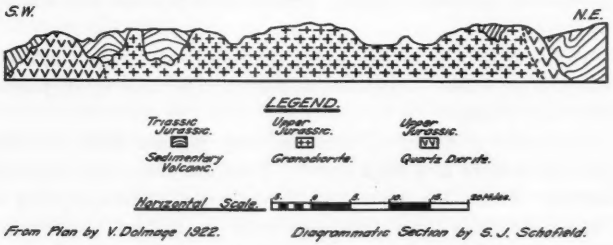

FIG. 3. S. W.–N. E. cross section, Coast Range Batholith, Observatory Inlet, B. C.

In the neighborhood of the Britannia mine the rock is the quartz diorite of the Pacific Belt. It is massive, of light gray color with pinkish tones in some places. The mineral constitu-

[4] S. J. Schofield and G. Hanson, Geol. Surv. Can., Mem. 132, 1922, p. 22; V. Dolmage, Geol. Surv. Can., Summ. Report, 1922, p. 154.

ents are andesine and quartz with minor amounts of hornblende or mica or both these minerals. In places orthoclase is present and the rock approaches a granodiorite in composition.

Gabbro Dikes.—These dikes are well exposed on the 1,000-foot level. Outside the shear zone the gabbro dikes are fine-grained green rocks so highly metamorphosed that its original character can not be detected. Where they cross the shear zone they are altered to a very dark green schist.

Diorite Dikes.—These dikes are found principally in the hanging wall portion of the shear zone. They are composed of a fine-grained mixture of plagioclase and hornblende. As a rule they follow the direction of shearing both in strike and dip. In some cases small dikes of similar material cross the shear zone.

They split and unite along the strike and up the dip (Fig. 2). In the upper levels these hanging wall dikes are 50 feet wide but diminish in size to 16 feet in the lower levels. These dikes are important factors in controlling ore deposition since important ore bodies occur in the chlorite schist where two such dikes unite above the ore body. Also the ore bodies in the hanging wall portion of the shear zone are controlled in position and attitude by these dikes.

Aplite Dikes.—Only one aplite dike was seen in the neighborhood of the mine. It is white in color and is made up of plagioclase and quartz.

Lamprophyr Dikes.—These are very narrow dikes of fine-grained texture and black color. They are very fresh and unaltered. Under the microscope they are seen to be composed of labradorite with mica and hornblende as colored constituents. The age of these dikes is unknown except relatively. They cut the chlorite schist. They may be Tertiary in age but for the present they are considered to belong to the later phase of the Coast Range batholith.

Glacial Drift.—The valley bottoms are floored with a great thickness of glacial drift composed of sand and gravel in which are embedded many large boulders.

THE VEIN SYSTEM OF BRITISH COLUMBIA.

A tabulation of the strikes of the mineral veins of British Columbia omitting those which are parallel to the bedding planes of the sedimentary rocks will show two well defined directions. This elimination is justified on structural grounds since bedding planes as lines of weakness have no general direction and are due to a cause entirely distinct from the cause of fissures and shear zones which cut across the strike of the formations. This elimination leaves the fissures and shear zones which are related to dynamic forces as well as to the structural foundation of the whole of British Columbia.

These two general directions which are thus brought into prominence are

1. Northwest,
2. Northeast.

In some cases the trend of the fissures and shear zones vary 10 to 15 degrees on either side of this general direction but for materials so different in strength and physical character as the rocks found near mineral veins, this approximation is remarkable for its steady repetition.

Origin of the Fractures.—Becker and Van Hise have shown that compression forces acting upon such materials as granite produce normally two sets of fractures at an angle of 45° to the direction of the applied force and therefore at 90° to each other. Such fractures as designated above trending in N.E. and N.W. directions apparently satisfy the conditions for the operation of a compressive force. From other supporting evidence it is indicated that the compressive force which resulted in the above mentioned fractures originated in the Pacific ocean.

It may be noticed that the fiord system of British Columbia is related in direction to these two major systems of fractures. These fracture zones formed lines of weakness along which erosion took place more readily and hence were the foundation for the drainage pattern not only of the Coast of British Columbia but also for the Interior drainage as well.

NATURE OF THE ORE AND GANGUE.

The chief minerals are the primary sulphides chalcopyrite and pyrite. Near the surface these minerals have been oxidized to limonite and azurite. It is reported that some native copper and chalcocite occurred near the surface in such relationships as to suggest its secondary origin. In the Bluff ore body considerable quantities of zinc blende and galena were found. The gangue consists of quartz, silicified chlorite schist, and chlorite schist.

An interesting occurrence of gypsum [5] is associated with the foot wall slates on the 1,000-foot level. The gypsum is in the form of a vein 15 to 20 feet wide, striking parallel to the schistosity of the slates. Gypsum was also noticed as small stringers in the silver schist of the hanging wall portion of the Fairview mine.

Since the gypsum occurs at least 1,000 feet below the surface and in a rock originally of igneous origin, it is believed that the sulphate waters which gave rise to the gypsum were of igneous origin.

Associated with the gypsum in some, but not in all cases, native sulphur was noted as small seams a fraction of an inch in width. This sulphur is considered to be of igneous origin.

Barite of massive character was seen in the Jane ore bodies.

The following table shows an average analysis of the ores from the various mines.

Mine.	Ozs. Per Ton.		Per Cent.			
	Gold.	Silver.	Copper.	Insol.	Iron.	Zinc.
Bluff	0.06	0.22	1.86	65.4	10.5	0.97
Empress	0.05	0.20	2.37	66.4	9.5	0.39
Fairview	0.01	0.24	2.99	73.7	6.6	0.41
Victoria	0.003	0.35	4.42	56.8	12.7	0.80

ORIGIN OF THE ORE BODIES.

The ore bodies of the Britannia mine are associated with chlorite schist, cut by the quartz diorite of the Coast Range

[5] S. J. Schofield, Geol. Surv. Can., Summ. Rept., 1918, p. 56 B.

batholith with which most of the copper deposits of the Pacific Mineral Belt of British Columbia are found. Evidence to support this is gained from the examination of the quartz diorite in the immediate vicinity of the mineralized shear zone of the Britannia mine. This quartz diorite contains as a primary and accessory mineral chalcopyrite and pyrite. The ore is later than all the intrusion rocks except a few small dikes and the solutions which gave rise to the ore bodies are believed to come from the quartz diorite of the Coast Range batholith of Upper Jurassic Age. The solutions which came from the quartz diorite brought in copper, iron, gold, silver, zinc, sulphur, silica and in its later stages calcium and sulphate waters and possibly barium. The minerals indicate primary deposits of intermediate vein zone.

These solutions rising along the weakened and permeable shear zone of chlorite schists were concentrated by the pitching wedges of chlorite schists which had a sloping roof, so to speak, of impermeable slates. These impermeable pitching roofs (Fig. 1) formed the dam which localized the ore bodies in the wedges. In a similar way the split dikes formed a catchment for the rising mineralizing solutions and caused a concentration in the chlorite schists below the impermeable ridge of dike material. Also the dikes which dip 70° to the south acted as a dam for the rising solutions.

ORE BODIES.

General Considerations.—The ore bodies of the various mines occur scattered in certain well defined areas along a shear zone of chlorite schist extending N. 45° W. for a distance of at least 6 miles. The shear zone has an average width of 1,500 feet and dips from 45° to 70° to the south.

The dominant structure which governs the localization of the various ore bodies in the shear zone is the occurrence of three wedge-like masses of chlorite schist (Fig. 1) offshoots of the main chlorite schist belt, which are embedded in the slates forming the footwall of all the mines. These wedges or noses of chlorite schist pitch 45–60 degrees to the west and govern the

pitch of all the ore shoots in the schist. The three mines associated with these three wedges from west to east are the Bluff-Fairview, the Empress and the Victoria. The Jane mine which occurs west of the Bluff ore body has an entirely different setting in that it occurs entirely in the sedimentary series.

These relationships can be seen in Fig. 1.

Jane Mine.—The Jane ore bodies are replacement deposits in the sedimentary series in which the argillaceous quartzites of the Britannia formation are replaced by chalcopyrite and pyrite. Considerable amounts of galena and zinc blende are distributed irregularly throughout the ore bodies. The gangue is quartz, silicified argillaceous quartzites and possibly barite.

There is no definite vein structure, the ore bodies occurring as irregular masses covering an area of 300 feet long, 250 feet wide with a depth of less than 300 feet.[6] The relationship of the Jane to the Bluff is such that it appears to be an offshoot from the Bluff ore body although it is not connected with it in any structural way. It occurs 900 feet W. of the Bluff-Fairview.

The Bluff Mine.—The Bluff and Fairview mines are associated with the largest and most westerly wedge-like mass of chlorite schist which controls the ore bodies in pitch, strike, and dip.

The Bluff ore bodies are characterized by a very large mass of highly siliceous ore whose boundaries are purely commercial, the ore body gradually passing outwards into a dense hard chert-like quartz which breaks with conchoidal fracture. This rock resembles the "flinty" rock described by Bateman[7] from the Beatson mine in Alaska. The ore body has a maximum length on the 1,200-foot level of 500 feet with a width of 250 feet. It outcrops above the 1,000-foot level and extends at least to the 2,200-foot level with excellent possibilities for ore beneath this horizon.

The average dip of the whole body is 60° to the south with a general pitch of 60° to the northwest.

The ore minerals are native gold, pyrite, chalcopyrite, zinc

[6] C. P. Browning, *Trans. Can. Inst. of Mining and Metallurgy*, 1922, p. 200.

[7] Alan M. Bateman, ECON. GEOL., vol. 19, 1924, p. 338.

blende and galena in a gangue of cherty quartz. Gold and silver values are persistent but are lower than in the Jane ore bodies.

The cherty quartz is a replacement of the chlorite schist by silica. As mentioned above the chlorite schist is a sheared quartz porphyry, all gradations being found from the massive quartz porphyry through a gneissic quartz porphyry to chlorite and sericite schist. Fragments of the slates of the Britannia formation are found in the quartz porphyry as well as in the chlorite schist.

Between the Bluff ore body and the vein-like masses of the Fairview mine occurs a barren quartz zone which shows all transitions from the cherty quartz in which ghost-like patches of chlorite can be seen, through silicified chlorite schist into chlorite schist itself. Also silicified fragments of slate are seen in the chert itself. Thus all evidence points to the alteration of the chlorite schist by silica bearing solutions into a cherty quartz by replacement.

The Fairview Mine.—The Fairview mine is characterized by two kinds of ore bodies, (1) a vein system which is mineralized over a distance of 1,500 feet with a width of 500 feet. The veins, 12 in number, strike N. 55° W. and dip 72° to the south and the ore bodies in the veins pitch 45° to the northwest. These veins from 10–70 feet wide are mineralized with pyrite and chalcopyrite in a gangue of quartz and silicified chlorite schist. Zones of chlorite schist, usually barren, of no commercial value, occur separating the veins. The veins in this mine, especially in the northeastern part of the mine, cross the shearing at a small angle so that in walking westward along a drift, the mineralization appears to be constantly going into the hanging wall, the mineralization appearing at the intersection of the veins and the shearing. (2) Large irregular replacement deposits. These ore bodies are associated with the diorite dikes which occur usually in the hanging wall of the shear zone. The dikes in the immediate vicinity of the ore bodies are silicified and partly replaced by the ore minerals, pyrite and chalcopyrite. A favorite position for the occurrence of these ore bodies is below the union of two

dikes, as well as under the diorite dikes, thus making the dike the hanging wall of the deposit.

Empress Mine.—The Empress Mine occurs about 1,000 feet east of the Fairview. The ore bodies are associated with a wedge-like mass of chlorite schist embedded in the footwall slate similar in structure to that of the Bluff-Fairview. The ore bodies, which occur as lenses in the chlorite schist, have a maximum length of 100 feet and mineralization extends to a width of 75 feet. The general strike and dip of the ore bodies conform to those of the schists which are N. 45° W. and 65° to the south.

The mineralization consists of chalcopyrite and pyrite with quartz and silicified chlorite schist as gangue. When approaching the edge of the wedge which pitches 45° to the northwest, the ore bodies become more siliceous. The ore bodies correspond in pitch with the wedge.

Victoria Mine.—The Victoria Mine is the most easterly deposit, and the ore bodies are also associated with a wedge of chlorite schist embedded in the footwall slates. The wedge pitches 65° to the northwest. The ore bodies are in the forms of veins which coalesce in the thin part of the wedge-like mass of schists and become more siliceous. They strike N. 45° W,, and dip to the south parallel with the planes of schistosity of the chlorite schist.

Further ore bodies are known east of the Victoria, but so far have not been opened up.

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A GOLD–COBALTITE–LODESTONE DEPOSIT, BRITISH COLUMBIA, WITH NOTES ON THE OCCURRENCE OF COBALTITE.

W. L. UGLOW AND F. F. OSBORNE.

THE Windpass Mine, in the North Thompson Valley map-area of British Columbia, presents a number of features which are unique among the ore-deposits of the province. The mine is situated at an elevation of 5,300 feet, on the uplands, near the eastern margin of the Interior Plateau. At present it is accessible from the town of Chu Chua on the Canadian National Railway by a wagon road of about six miles and then a pack-horse trail of about equal length.

GENERAL GEOLOGY.

Rocks.—The rocks near the mine are summarized in the following table of formations.[1]

FORMATION		LITHOLOGY
MESOZOIC (?) JURASSIC (?)	BALDIE BATHOLITH	GRANITE PORPHYRITIC GRANODIORITE
	SILL	QUARTZ DIORITE—PYROXENITE
INTRUSIVE CONTACT		
PRECAMBRIAN OR EARLY PALÆOZOIC	FENNELL	ELLIPSOIDAL GREENSTONE WITH LENTICULAR MASSES OF THINLY-BEDDED GRAY OR WHITE CHERT. VOLCANIC BRECCIA

The quartz diorite-pyroxenite sill[2] is either differentiated or composite and varies from a pyroxenite on the east side to a dark

[1] Uglow, W. L., "The Geology of the North Thompson Valley Map Area, B. C," Geol. Surv., Can., Summ. Rept., 1921, Part A, pp. 72–106.

[2] Uglow, W. L., *loc. cit.*, p. 80.

gray mottled quartz diorite on the west, where the ore bodies occur. On the west, the sill is in steep contact with a narrow band of the thinly-bedded chert of the Fennell formation, locally called the " white dike," west of which are the greenstones of the Fennell formation. On the east, the sill is undercut by the intrusion of the Baldie batholith, but both sill and batholith probably belong to the same period of igneous activity, the sill representing an earlier basic intrusion.

Petrography of the Sill.—The quartz diorite, or more acid facies of the sill, shows some interesting features in thin section. The commonest mineral is andesine occurring as idiomorphic crystals which to a large extent are clouded with alteration products, too fine to be identified, but possibly a mixture of paragonite and zoisite. Along its margins and fractures, the andesine crystals have been replaced by more acid plagioclase, about albite-oligoclase. The new feldspar is, as a rule, clear and unaltered so that it has an appearance of higher relief against the andesine but occasionally ghosts of the altered andesine may be observed. A matrix of acid plagioclase in micrographic intergrowth with quartz surrounds the altered andesine. Considerable hornblende occurs in the rock, but where it is in contact with the new feldspar or the micrographic intergrowth it has a frayed or shredded appearance with weak pleochroism similar to actinolite.

Mineralogy.—The minerals of the Windpass vein include free gold, cobaltite, lodestone, bismuthinite, bismuth, chalcopyrite, magnetite, pyrite, pyrrhotite, quartz, native copper and calcite. The chief value of the ore is in its gold and copper content, and silver is of less importance.

THE ORE DEPOSITS.

Structure and Occurrence of Ore.—The deposit is a mineralized shear zone in the quartz diorite facies of the sill that varies in width from one to ten feet. Angular to subangular fragments of quartz diorite cemented by vein material, occur within the shear zone where the zone is thickest, but where it pinches, the

brecciated appearance disappears and clayey gouge without appreciable mineralization is developed.

At its west end, the shear zone enters the bedded chert of the Fennell formation, anastomoses and loses its metallic content, while to the east it is crossed by another shear zone at a flat angle, beyond which no ore has yet been proved. Within the shear zone the ore shoot seems to plunge steeply to the east, but it has only been developed to a depth of 150 feet below the surface.

There is some mineralization in the wall rocks and quartz diorite fragments of the shear zone, indicating a replacement; but in most cases the minerals that occur in this way are the hard minerals of the deposit, such as magnetite, cobaltite and pyrite. In these cases, the rock minerals are replaced in the following order: hornblende, micrographic quartz-plagioclase, and lastly andesine, as a result of which andesine frequently appears like "phenocrysts" in a metallic matrix.

Zoning of the Minerals.—Within the ore shoot there is a well-defined zoning of the vein minerals. The core of the shoot is characterized by a concentration of cobaltite with high gold content, associated with magnetite and chalcopyrite in the form of a massive lode. This grades longitudinally through a chalcopyrite-magnetite zone followed in turn by magnetite, pyrite-pyrrhotite-chalcopyrite, and quartz-pyrite zones.

Gold-Cobaltite Shoot.—A considerable concentration of cobaltite occurs in the central part of the ore shoot, but it is confined to a horizontal length of vein of ten to fifteen feet. It is found in small masses of pure mineral as large as walnuts mixed with chalcopyrite and magnetite, pieces of ore as large as one foot in diameter containing up to ten per cent. by volume of cobaltite. Gold values, amounting to several ounces per ton of ore are associated with this shoot. Bismuth and bismuthinite occur, and these appear to be related to the localization of gold near or in the cobaltite. Chalcopyrite was found to be in cutting relations to the cobaltite in all cases examined where free gold was present. Cobaltite also tends to spread outside the shear zone and to replace the wall rock, subsequently to its replacement by magnetite.

Lodestone.—The variety of magnetite, known as lodestone, occurs abundantly near the surface, particularly near the eastern and western extremities of the ore shoot. It seems to occupy a position, with respect to the mineral zoning, corresponding to that occupied by pyrrhotite on the tunnel level (100 feet below the surface), that is to say, it is found chiefly around the margins of the ore shoot just inside the quartz zone, and appears to be in some sense a surface expression of underlying pyrrhotite. The exact nature of this relationship has not been determined, since the zone of transition between this near-surface lodestone and the underlying sulphides has not been revealed by development.

The lodestone is black with a bluish tint, porous and rusty with iron hydrate, and possesses strong polarity and magnetic properties. Free gold is abundant in it, and can easily be obtained from it by panning. Under the microscope, the lodestone shows a rough pitted surface without visible structure. Bismuth and bismuthinite also occur scattered through it, and are visible to the naked eye.

Mineralogy.—The sequence of the minerals of the deposit is shown graphically in the following scheme, with the older ones on the left:

Magnetite
Pyrrhotite
Pyrite
Cobaltite
Chalcopyrite
Gold
Bismuthinite
Bismuth
Quartz
Calcite
Native Copper

Magnetite (dense, black, crystalline variety, without polarity) is the earliest metallic mineral, and constitutes a large part of the mineralization, both within the shear zone and as impregnations within the wall rocks. Pyrrhotite replaces part of the magnetite, and also the rock within the shear zone, but is not commonly

found in the wall rocks. Pyrite replaces the earlier minerals, as well as some of the shear zone rock. In part of the vein it is found with a porous, honeycomb structure, evidently produced by the solution and removal of the rock from what are now the spaces in the "honeycomb." In some of the pyrite a uni-directional cleavage or parting is developed, probably as a result of unequal stresses.

Cobaltite occurs in idiomorphic crystals replacing earlier minerals especially magnetite and country rock. The mineral is recognized under the microscope by its hardness, pinkish white color, and usually idiomorphic crystal outline. The perfect cubic cleavage usually so evident in the hand specmen is not visible on the unetched surface.

Chalcopyrite is younger than the cobaltite and replaces all the earlier minerals of the deposit. In the earlier stages of its deposition chalcopyrite was deposited principally along older mineral contacts and is characterized by a small amount of free gold. Before the deposition of the chalcopyrite was complete, however, a movement produced a slight fracturing of the ore, and with the chalcopyrite subsequently deposited is associated a larger amount of bismuthinite, bismuth, and free gold. The exact age relations between the bismuthinite, bismuth, and gold could not be ascertained because of the small amounts present; but, it is suggested that, since relatively more gold than bismuth minerals was found of contemporaneous deposition with the chalcopyrite, the gold began to deposit before the bismuth and bismuthinite. The bismuth minerals and gold continued to deposit for some time after the deposition of chalcopyrite ceased because they are found in veinlets cutting it, as well as traversing the brecciated magnetite and replacing the country rock. In all cases noted bismuth was found to be closely associated with the bismuthinite and frequently to be enclosed by it.

Barren quartz veins cut and replace all the ore minerals, and veinlets of native copper and calcite, evidently of surface origin, are the latest minerals to form.

Genesis of Deposit.—The mineralization was at first believed to be due to contributions from the Baldie granodiorite batholith,[3] but later investigations relate it to the quartz diorite-pyroxenite sill itself for the following reasons: (1) the intimate association of the ore body with the sill, the failure of the values to occur in the vein, and indeed the dying out of the vein itself, where the latter enters the thinly-bedded chert on the west; (2) the fact that cobaltite is a mineral of basic affiliations and is characteristically found with basic igneous rocks; (3) the occurrence of other veins of similar type within the sill; and (4) the general similarity between the main metallic minerals (magnetite, chalcopyrite and pyrrhotite) and the endomorphic production of new acid feldspars, in connection with this quartz diorite sill and the diorite and quartz diorite intrusions that produced the contact metamorphic magnetite deposits near the west coast of Vancouver Island.

The solutions producing the mineralization were doubtless very thin, as shown by their ability to penetrate solid rock and preferentially replace certain constituents, like hornblende. The marked shearing and brecciation of the vein zone extends for several hundred feet east of the ore shoot, and was without question produced, not by the intrusion of an ore magma, but by faulting prior to mineralization. The paragenesis of the minerals indicates a progressive introduction and replacement of the vein minerals that is difficult of interpretation by any other means than tenuous solutions.

There are two interesting relationships exhibited by the gold that require some explanation. The first is the marked association of high gold content with the centrally located cobaltite shoot; and the second is the association, observed under the microscope, of gold, bismuth and bismuthinite near the boundaries of chalcopyrite. The gold content is highest within the cobaltite shoot, and assays reveal the fact that the occurrence of masses or blebs of cobaltite in the ore is coincident with a marked increase in gold content. The association, above-mentioned, of

[3] W. L. Uglow, Geol. Surv. Can. Summ. Rept., 1921, part *A*.

gold, bismuth minerals, and chalcopyrite seems to be genetic in the sense that bismuth and gold mineralization is related, but slightly subsequent, to copper mineralization; and, even in the cobaltite shoot more free gold was observed, in intimate association with the bismuth minerals, replacing brecciated magnetite, than in the cobaltite itself. It is suggested, therefore, that, since the cobaltite is usually replaced only to a small extent by gold, it acted in some way as a precipitant of gold in other minerals (chiefly magnetite) without being much replaced itself.

AN ANALOGY BETWEEN THE WINDPASS VEIN AND SOME OF THE COBALT-SILVER VEINS OF NORTHERN ONTARIO.

An interesting analogy is suggested between some of the general features of the geology and mineralogy of the Windpass vein and of some of the cobalt-silver veins of Northern Ontario; making some of the principal points of comparison worthy of mention.

1. The geological columns, in the two localities, are quite similar in their lithology, although their positions in geological history may be quite different. The Keewatin greenstones underneath the diabase sill at Cobalt are analogous to the greenstone pillow lavas of the Fennell formation, which lie to the west, and probably below the Windpass sill. The diabase sill at Cobalt, with quartz in micrographic intergrowth is very similar to the quartz diorite sill at the Windpass, in which the main part of the quartz is in similar intergrowth; while specimens from the two localities can scarcely be differentiated by the naked eye, particularly since an imperfect ophitic structure may be seen in the quartz diorite.

2. In each case, the mineralization is genetically related to the sill, although at the Windpass this relationship has not been so firmly established as in northern Ontario.

3. There is a partial similarity in the mineral associations in the two sets of veins—cobaltite and bismuth being common to both, with large amounts of silver and calcite and minor amounts

of quartz at Cobalt, and large amounts of gold and quartz and minor amounts of silver at the Windpass.

4. The Cobalt sill is noted for aplitic differentiates which, as far as known, do not occur as separate entities at the Windpass. Probably in their stead, there occur at the Windpass the later acid plagioclase margins (described under Petrography above) that replace the older andesine and micrographic eutectic and seem to represent a late-stage differentiated residuum from the mother magma.

THE GEOLOGICAL OCCURRENCE OF COBALTITE.

A brief survey of some of the literature covering cobaltite occurrences was undertaken in order to ascertain what are the geological and mineralogical affiliations of the mineral and to obtain, if possible, some perspective on the uniqueness of the Windpass vein.

This review brought out a few points that are of more than local interest. In the first place there seems to be an inclination on the part of the mineral to be genetically related to basic rocks, such as quartz diorite, diorite, andesite, amphibolite, diabase and gabbro. Another feature is the preferential association with, or replacement of, minerals relatively high in magnesium, the common examples being mica, talc, actinolite and hornblende. Even where quartzite is the host rock, the cobaltite shows a preference for the salite facies where magnesium-bearing minerals are common. This association may be accidental due to the commonness of magnesium in basic rocks, or it may be due to the fact that ferromagnesian minerals are the most easily replaced.

Gold is associated with cobaltite where the gangue is quartz, as at the Windpass, while silver is developed where the carbonate gangue is predominant, as at the Broken Hill Consols mine, New South Wales, and in Northern Ontario. Where both quartz and calcite occur, gold values most often predominate, but occasionally silver is more important. There seems to be a scarcity of nickel minerals where gold is important.

In the cases where the paragenesis is recorded, cobaltite is formed before the gold, and is usually separated from it by the deposition of one or more minerals. Gold is usually associated with chalcopyrite or bismuth, although it seems to be localized by the cobaltite. The same conclusion seems justified with respect to the occurrence of silver as at the Consols mine, New South Wales.

UNIVERSITY OF BRITISH COLUMBIA,
VANCOUVER, B. C., CANADA.

EDITORIAL

GEOPHYSICAL METHODS IN ECONOMIC GEOLOGY.

Progress in geology, since it first emerged as a science from the broad field of natural philosophy, has been due almost wholly to increased ability to interpret and to advances in knowledge resulting from accumulating observations. There has been but little progress in ability to observe; but little extension of the geologist's powers through the finding of new tools. The geologist today goes into the field with his hammer, compass-clinometer, collecting bag, and notebook, as did the Adam of all geologists, whoever he may have been.

There has been some refinement in technique. The plane table has replaced the compass-clinometer for detail work and the modern high-powered microscope the old inferior lens, but, as with most other improvements, these have been chiefly in the nature of refinement or extension of the use of old methods rather than the discovery of new methods of observation.

We have now found new tools and it may well be that they will make possible such an extension of our powers of observation as to mark a new era in the science. These tools are the various instruments for measuring variations in gravity, in the earth's magnetic field, and in the elasticity, electrical properties, and temperature of various rock masses—the geophysical instruments.

This comparatively new field of earth study is new, not so much because the measurements of the various physical characteristics of the earth's crust have not already been made as because instruments suitable for such studies are just now coming into the hands of the geologist and enabling him to make surveys which formerly were attempted only by such organizations as the Coast

and Geodetic Survey or the Carnegie Geophysical Institution. This field of observation, important as it may be to the entire science of geology, is particularly interesting and important to the economic geologist.

Attempts to find some physical aid in prospecting for minerals are probably but little less old than mining itself. Water witching and the use of the divining rod doubtless come down to us from the days of the tribal medicine man who was the custodian and practitioner of the arts and sciences as well as of the religious mysteries. Their use is known to have been practiced during the latter part of the sixteenth century. The first illustrated edition of Agricola, published in 1580, portrays a master of the forked twig practising his mystery in the fashion most approved by his modern descendants.

Like the alchemist's dream of transmuting baser metals into gold, the development of a fairly reliable divining rod, although of somewhat limited use, seems to have been fairly realized by modern science, for the geophysical methods are the scientific divining rods of the modern prospector—the economic geologist. The past few years has seen their introduction and use with great success in solving problems of prospecting not susceptible to other and simpler solutions.

The application of geophysical methods to problems of mining and economic geology are not entirely new. The first attempts at electro-magnetic prospecting were made in Cornwall as early as 1830; investigations were made in Nevada in 1882; and, as early as 1873, Major T. B. Brooks, of the Michigan Geological Survey, writes: "The idea of applying magnetic science to geology is not at all new."

Baron Roland von Eötvös, Professor of Physics at the University of Budapest, in 1887 demonstrated the possibility of making gravitational surveys by the use of his balance, a simple modification permitting field use of the older Coulomb torsion balance, which had been in laboratory use since the eighteenth century. The Eötvös balance has been in practical use for geo-

logical purposes since 1891; its development for economic work has been accomplished in Hungary and Germany during the last fifteen years.

Seismic and electrical methods are of comparatively recent development and it is but lately that the economic possibilities of a study of geothermal gradients has been demonstrated.

It is surprising that so little is known generally by geologists regarding this new and important branch of their science. In reviewing the development of the geologic sciences during the past year, so eminent an authority as the Chief Geologist of the United States Geological Survey and retiring vice president for Section E of the American Association for the Advancement of Science fails to notice the development of geophysical methods, yet it was a year of outstanding proof of the utility of such methods in the Gulf Coastal Plain—a proof strongly suggesting their usefulness in other areas after further study and experiment.

The outstanding and most broad-scaled success in the application of geophysical methods to the problems of prospecting has been during the past few years in the search for new salt domes in coastal Texas and Louisiana.

The late Anthony F. Lucas, by the successful completion of his Spindletop gusher in early 1901, established the importance of the salt dome in the United States as a type of structure containing petroleum deposits. Sulphur deposits associated with the same type of structures in the same areas, as soon as mining became practicable through the development of the Frasch process, became important enough to dominate the world's sulphur markets. The recent discovery of potash salts in one of the domes suggests the possibility that at some future date this mineral may be found in deposits of commercial importance. Several of the domes are being mined for salt. The great economic importance of these domes is quite apparent.

The coastal salt domes occur generally in a flat, featureless region of monotonous plain; a region of no rock outcrops of significance. Until recently it was believed that the geologist could be of little or no assistance in the search for new domes.

Excluding the so-called Interior domes and the domes of southwestern Texas, there are some 46 known salt domes in the coastal area. Of these, 33 were proved during the few years of vigorous drilling campaign which followed the discovery of the Spindletop gusher in 1901. In the score of years which elapsed before the introduction of the torsion balance and seismograph, the total result of considerable prospect drilling based upon such vague surface indications as sulphur-water wells, gas seepages, occurrences of "paraffin dirt," slight topographic irregularities, or pure hit-or-miss methods was the discovery of 5 additional domes.

The Eötvös torsion balance was introduced into this area near the end of 1922 and surveys of many of the proved salt domes was made. Results having been fairly satisfactory, the instrument was used to prospect areas in which salt domes were suspected, and, in February, 1924, drilling proved the first salt dome to be found in this area by such methods. The use of torsion balances had already become more common and, early in 1924, seismographs were introduced into the area. With continuing success, the use of these two methods increased rapidly until now the region is in the midst of a prospecting campaign of a size and intensity not previously experienced. This wave of prospecting is also peculiar in that it is concentrated in land leasing and examination of lease-hold by geophysical methods rather than in drilling.

The net proved result of the geophysical work in 1924 and 1925 is the discovery of 7 new domes—more new domes than had been discovered in the previous twenty years. Also, there are doubtless many additional domes already discovered but yet to be proved. Geophysical methods have achieved a brilliant success in this area.

We are just beginning the use of geophysical methods. They are today receiving their greatest development and application in the oil regions. They will be equally important in the mining industries and will aid in solving problems of pure science which now appear to have no solution.

We have new tools, but we have only the most elementary knowledge of how to use them. Further improvement in the de-

sign of the instruments is not needed so badly as we need to learn how to interpret results which can be obtained with present instruments. We need to build up a background of experience against which we can judge our results. The physicists who build and operate the instruments and compute the results are far ahead of the geologists whose business it is to interpret the results. Here is a new field of an importance possibly greater than we can even estimate today. It is worthy of the attention of every geologist.

E. DEGOLYER.

DISCUSSION AND INFORMAL COMMUNICATIONS

THE MANSFELD KUPFERSCHIEFER.

Sir: In your issue for December, 1925 Dr. P. D. Trask presents a very thorough review of the current literature dealing with the origin of the Mansfeld Kupferschiefer, Germany. The descriptions of the microscopic structure of the normal undisturbed strata as given by Schneiderhöhn and Hoffmann is of special interest from the standpoint of the syngenetic origin of the ore. It is stated that the sulphides occur as isolated, minute grains, lenses or small rounded masses which grade into one another. All are small in size, ranging from a few micra to several mm. in their greatest dimension. These minute structures are completely surrounded by clay and bituminous material.

Structures very similar to those occurring in the copper-bearing shale have been produced by the writer in experimental work dealing with the action of sulphate-reducing bacteria in argillaceous sediments. When sulphate-reducing organisms are grown in a flask of clayey sediment saturated with a solution containing sulphates, colonies of bacteria develop in the mud throughout the entire flask. If iron is present in the culture solution, black amorphous iron sulphide is formed and occurs as minute seed-like grains in the mud associated with the colonies of bacteria. When only a limited amount of iron is available the clay retains its original color and the sulphide appears as conspicuous grains in the sediment where the colonies of bacteria develop. If the amount of iron in the solution is increased, the solution above the sediment becomes black due to suspended particles of iron sulphide and on the addition of a small amount of fine silt, the sulphide is carried to the bottom and forms a black layer or lamella in the sediment.

Schneiderhöhn refers to the great number of minute grains in the Kupferschiefer as mineralized bacteria that sank to the bottom of the sea after death. The experiments cited above show, however, that bacteria thrive and form colonies directly in the mud, and would therefore be entirely surrounded by clay "even to the most minute irregularities of their surfaces." The texture of the copper-bearing shale suggests that bacterial growth in the organic muds that gave rise to the bituminous shale, and in the water near the bottom of the sea, reduced both the iron and copper solutions that were present as the sediments accumulated.

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ASBESTOS DEPOSITS OF CYPRUS.

Sir: In connection with the discussion on asbestos deposits started by the paper of Alan M. Bateman, Mr. John A. Dresser asks (in your issue for December, 1925), whether in my analyses of specimens of harsh and soft fibers of Cyprus asbestos [1] I found a difference in their water content. No difference worthy of note was found and my opinion is that even the difference noted by J. I. Donald [2] is due to the different pressures under which the chrysotile was formed. In the sulphur mine of Passarello, Sicily,[3] I studied the transformation of sulphur into gypsum and have found that the enormous pressure developed by such a transformation had increased the specific gravity of the gypsum. I also noted that the water content was smaller where smaller pressure was to be expected, as the specific gravity was also lower, and for such a reason Mr. Donald's results seem in no way connected with the physical condition of the chrysotile he analyzed.

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[1] C. L. Sagui, "Asbestos Deposits of Cyprus," ECON. GEOL., vol. XX., 1925, 371–375.

[2] *Jour. Gen. Min. Assoc. of Quebec,* 1891, p. 28.

[3] C. L. Sagui, "The Sulphur Mines of Sicily," ECON. GEOL., vol. XVIII., 1923, 738–745.

REVIEWS

The Geology and Mineral Industry of Western Australia. By A. Gibb Maitland and A. Montgomery. Geological Survey of Western Australia, Bull. No. 89, 119 pp., 29 figs., 2 maps. Perth, 1924.

General Geology.—The area of Western Australia is close to one million square miles, practically one third the area of the entire commonwealth. Within it are recognized three principal topographic divisions: (1) the Coastal Plain; (2) the Hill Ranges; and (3) the Plateau and Plains of the Interior.

The Coastal Plain fringes the coast with gentle seaward slope and a width commonly of 60 to 70 miles, broadening to 200 miles along the south coast. Its inner margin in places rises 600 to 1,000 feet above sea-level; its outer margin is the edge of the continental shelf, at a depth of about 600 feet below sea. Its rocks are Mesozoic and Tertiary sediments.

The Hill Ranges mark the transition from the Coastal Plain to the Plateau and Plains of the Interior. In the southwest part of the state the Hill Ranges are separated from the Coastal Plain by a great fault-scarp, the Darling fault traceable for 300 miles north and south of Perth, and averaging about 1,000 feet in height. The Hill Ranges attain an elevation of 4,000 feet. The rocks are mainly granite and metamorphic rocks, and most of the agricultural lands of the state lie within this province.

The Plateau and Plains of the Interior constitute by far the largest part of the state and average about 1,400 feet in elevation, though some portions reach 4,000 feet. The rainfall is small and streams intermittent, and numerous shallow basins are occupied by salt lakes or salt flats. Wind erosion predominates. This is the principal mineral belt of the province.

Stratigraphy—One of the most fundamental features of the geology of Western Australia is its similarity in structure and constitution of its rocks to India, South Africa, and Madagascar. In age they range from Archean to Recent. Pre-Cambrian rocks occupy large portions of the Plateau tract in the central and southwest parts of the state. Especially noteworthy among the rocks classed as Pre-Cambrian is the presence of great composite batholiths of granite which include crystalline schists and which have not yet been deeply truncated by erosion. The granites are traversed by many great dikes of white quartz, which probably represent

the final ultra-acid product of the differentiation of the granitic magmas. With these granites are associated, areally and genetically, the most important metalliferous deposits of the state. Noteworthy, too, is the occurrence in the Archean of cherts and brilliantly colored jaspers, grading into hematite ores. The presence of such thick and extensive deposits of iron oxides associated with cherty silica in Pre-Cambrian rocks in so many parts of the world, and their rarity in younger rocks, points clearly to conditions fundamentally different from those in Post-Cambrian times, and indicates that uniformitarianism as a working principle for the geologist can not be pushed back indefinitely into the past.

The most widespread formation of Western Australia is the Nullagine formation, which rests, with gentle dips, on highly inclined Pre-Cambrian rocks. It consists of sediments that are unmetamorphosed, but as yet have yielded no fossils.

Fossiliferous rocks definitely known to be Paleozoic occur mainly in the northeast part of the state and include rocks of Cambrian, Ordovician, Devonian, Carboniferous, and Permo-Carboniferous ages. Of especial interest is the boulder belt in the Permo-Carboniferous that has been interpreted by some geologists as a tillite. I quote Maitland's statement concerning it:

"Interbedded with these Permo-Carboniferous rocks is a very persistent boulder bed, the component pebbles of which are covered with striæ of such a nature as to suggest that they owe their origin to ice action. Sections occur which show that this bed does not attain any great thickness, and that it is crowded with pebbles and boulders of granite, etc., embedded in a calcareous, fossiliferous matrix, which contains fragments of *Spirifera, Productus,* and *Polyzoa,* in addition to *Aviculopecten tenuicollis.* The fossil contents imply a marine origin for the boulder bed. It, therefore, can hardly be a glacial moraine, and it is more than likely that the materials were transported by floating ice, which deposited its burden on the sea floor. Whenever seen *in situ* it has been found that this glacial boulder bed (the Lyons Conglomerate) does not lie quite at the base of the Permo-Carboniferous rocks as developed in Western Australia" (pp. 31–33).

This conglomerate bed has been traced for a distance of about 200 miles.

Among the younger rocks the laterites, which seem to range from Tertiary to Recent, are especially noteworthy.

"The laterites consist largely of hydrated oxide of iron and alumina, producing on the one hand deposits of iron ore, and on the other bauxite. In some localities the deposition of secondary silica in the lateritic deposits produces what are practically quartzites. These, by an increase in the ferruginous coloring matter, pass into a jasperoid form of laterite.

There are thus three forms of laterite: an aluminous, a ferruginous, and a siliceous, the composition being liable to vary considerably over a small area, it being governed largely by the nature of the underlying rocks" (p. 48).

"The laterites are of considerable economic value as sources of iron and aluminium. Some have been utilized as a source of iron ore for fluxing purposes, owing, however, to the ease with which they can be smelted rather than on account of their richness or purity. Others have proved to be highly aluminous, approaching very closely in composition the bauxites of Europe, America, and India, which now form the chief source of aluminium" (p. 49).

Economic Geology.—The mineral deposits of greatest economic importance in Western Australia are gold, silver, coal, tin, copper, lead, and phosphates.

The recorded gold production of Western Australia to the end of 1922 amounted to nearly 35,000,000 ounces, if we make no allowance for unrecorded production. From 270 ounces in 1886 production increased to 2,000,000 ounces in 1903, but since then has steadily declined, to 53,000 ounces in 1922. The principal gold-producing area is in the southwest part of the state, in the Pre-Cambrian portion of the Plateau province. Throughout this province there is a general similarity in the gold occurrences, the deposits being grouped in several parallel elongate belts trending northwest and southeast. Within these belts individual primary gold deposits are relatively short lenticles, arranged *en eschelon* and occupying more or less elongated zones, along lines of crushing, brecciation, and shearing. In some fields the auriferous veins are closely associated with or grade into pegmatites and related rocks, and in all fields the areal association with granitic rocks is close.

The bulk of the production has come from lodes *in situ*, the chief producing center being the East Coolgardie field, which has yielded about half of the total output of the state. Within this field Kalgoorlie or Boulder is the greatest productive center. At Kalgoorlie masses of fractured rock of lenticular form and great length have been metasomatically replaced and also impregnated with quartz, so as to form workable ore bodies without well-defined walls. Workable ores have been proved to depths of 3,600 feet. The principal primary minerals of the lodes are pyrite, chalcopyrite, tennantite, carbonates of calcium and magnesium, hematite, magnetite, ilmenite, tourmaline, apatite, albite, and rutile, in addition to native gold and gold tellurites. In addition to these metasomatic ore bodies, there occur "reefs," consisting predominantly of quartz with subordinate sulphides. These are interpreted as fracture fillings and a few of them are saddle reefs, developed along the crests or troughs of folds. Another mode of gold occurrence, while of minor

import, is of considerable scientific interest because of its analogies with the deposits of the Witwatersrand, in South Africa. In several places the basal conglomerates of the nearly flat-lying Nullagine (late Pre-Cambrian?) formation are sufficiently auriferous to constitute ore bodies. These conglomerates overlie the steeply inclined lodes and "reefs" that have been described above. The auriferous conglomerate beds occur through a thickness of 300 feet of grits, sandstones, and conglomerates, the pebbles being rounded to subangular fragments of the underlying Pre-Cambrian rocks. Little weathered portions of the conglomerate carry pyrite in crystals, grains, and rounded or pebble-like forms. The parts that have been worked are rich in limonite and appear to be the product of weathering of the pyrite-rich portions, the gold invariably occurring in or lining the sides of cavities left by the oxidation of pyrite.

In places alluvial and residual deposits that are auriferous overlie the lodes and veins. In these most of the gold is clearly either detrital or residual, but it is interesting to note also the occurrence of dendritic or arborescent gold "which occurs filling irregular cracks" and is interpreted as a secondary deposit from meteoric waters.

The tin deposits of Western Australia have yielded, up to the end of 1922, concentrates valued at over five million dollars, mainly from the Greenbushes and Pilbara districts. Most of the production has come from the alluvial residual deposits, but the bed-rock occurrences are of greatest scientific interest. In the Wodgina district the pegmatite dikes which are offshoots of granitic intrusions are in places rich enough in cassiterite to constitute tin ore. These dikes vary in thickness from mere threads to veins 500 feet in width and of considerable length, and the cassiterite occurs in masses varying from minute grains to pieces 100 pounds in weight. Tourmaline often constitutes one third of the entire pegmatite mass, and tantalite, monazite, gadolinite, and euxenite are other associates.

The iron-ore resources deserve special mention. To quote Maitland:

> "The large iron deposits of the State are known to occur over an area extending from Kimberley to Cape Leeuwin. Some of them are probably equal in size to any other known deposits in the world, and are ultimately destined to form one of the State's most important assets" (p. 65).

The most important class of ores are hematites with a quartz gangue, forming lenticular masses in quartz schist, said to be of both igneous and sedimentary origins. The most noteworthy deposits are those of Yampi Sound, which are estimated to include over 97,000,000 tons of high-grade ore. At Wilgie Mia a lens of nearly pure hematite carries about 27,000,000 tons of hematite ore above the level of the surrounding plains. Many

similar deposits are also known. The iron-ore resources of the state are therefore much larger than has generally been realized, although, up to the present time, they have been used only as a flux in the smelting of ores of copper and lead.

Of interest, also, is an occurrence of alunite in the East Coolgardie Goldfield which has an auriole of alteration surrounding a boss of intrusive acid porphyry. The alunite occurs in horizontal or gently inclined veins varying in width from a mere thread to two feet and traversing a matrix of kaolinized slates and mica-phyllites of sedimentary origin.

Turning to the mineral fuels: No oil has thus far been found in West Australia, but coals constitute a very important resource and occur in the rocks ranging from Carboniferous to Tertiary, though mining has thus far been confined to Permo-Carboniferous coals of the Collie Field, in the extreme southwestern part of the state. To a depth of 2,000 feet it is estimated that the reserves of this field total three and one half billion tons. To the end of 1922 six million tons had been mined. The coals have been little disturbed by folding or faulting and are sub-bituminous in rank and non-coking, in places closely approaching lignites.

EDSON S. BASTIN.

Mikroskopische Physiographie der Mineralien und Gesteine. Bd. I. Erste Hälfte. By WÜLFING-ROSENBUSCH. Untersuchungsmethoden, 5th edition. E. Schweitzerbart'sche Verlagsbuchhandlung. Stuttgart, 1921–24, pp. xvi + 847. Plates 15. Figs. 680. Price (bound) $16.50.

Bd. I. Zweite Hälfte. By MÜGGE-ROSENBUSCH. Spezieller Teil, 5th edition. 1925. Pp. vii + 276. Plates 9, Figs. 28. Price $5.25.

It is unnecessary to dwell at length on the excellency of the volumes the titles of which appear above. It is quite enough to state that the new edition of Professor Rosenbusch's well-known work maintains the reputation of earlier editions.

The first half of the volume, revised by Dr. Wülfing, deals with the general principles of optical mineralogy. It contains descriptions of all the methods employed in determining the characters of minerals, and thoroughly discusses the causes of the results obtained. It is comprehensive and "up-to-date," and at the same time is critical. Dr. Wülfing's reputation for accurate work is a sufficient guarantee that his criticism of the various methods is of great value to those who contemplate employing them.

There is no book in optical methods in any language that approaches this one in its value to the petrographer and physical mineralogist.

The second half of the volume, revised by Dr. Mügge, deals with the

individual minerals. That portion which has been published treats of those crystallizing in the isometric, tetragonal and hexagonal systems, leaving those crystallizing in the other systems for a later publication.

This part follows closely the style of earlier editions. The number of compounds described is larger and each is discussed in a little greater detail than in former editions. The number of pages devoted to the minerals described is 276. In the 4th edition, the corresponding part numbered 121 pages, but the page was slightly larger.

The numerous illustrations add greatly to the clarity of the text. The plates are excellent.

W. S. BAYLEY.

The Earth and the Stars. By C. G. ABBOT. 264 pp. 46 figs. D. Van Nostrand Co., New York, 1925. Price $3.00.

This fine appearing volume makes another one of the Library of Modern Sciences, which is a popular series devoted to the influence of science on the development of civilization. The author has succeeded excellently in making it readable either for layman or scientist. It deals a little with the personality of astronomers and their instruments, and tells in simple language what the heavenly bodies are, their size, their motions, where they are, and what they are made of, and how knowledge of them is gained. Many of those things that seem an enigma are made clear to the lay reader. Eclipses are now understandable to everyone. Technical terms have been avoided, but for those who wish to know them a glossary is appended. An index makes the book more usable. It is a book that everyone should read, not as a matter of duty, but for the pleasure and education it will give. Also it can be used to advantage as collateral reading in college courses of geology and geography.

The publishers deserve credit for producing a handsome, well printed volume, though one wishes a larger type had been chosen. The author is to be congratulated on presenting so clearly a picture of our universe intelligible to everyone. We wish there were more such books.

ALAN M. BATEMAN.

Animals of Land and Sea. By AUSTIN H. CLARK. 276 pp. 740 figs. D. Van Nostrand & Co., New York, 1925. Price $3.00.

This book is one of the "Library of Modern Sciences—a popular series treating of their influence on the development of civilization," and is written by no less an authority than a Curator of the Smithsonian Institution. It is not a treatise involving a dry classification of animals,

birds and insects but interesting chats about them from the humanistic viewpoint. For example, note some of the chapter headings: Human Foods, Man as a Food for Animals (chiefly insects), Animal Flight, The Largest Living Creatures, Fresh Water Animals, Living Lamps, etc.

The book makes interesting reading for one who wishes to know how animals live, feed, and die, but who does not desire to go into classification and long names. It is written for the layman and older children, but the student can obtain much of value from it because of its excellent index. Its 740 figures tell much, particularly about insects. The volume is of handy size and its makeup is a tribute to good publishing.

A. M. B.

The Oil Industry. By ERNEST RAYMOND LILLEY, Asst. Prof. of Geol. New York Univ. 548 pages. D. Van Nostrand Co., New York, 1925. Price $6.00.

This interesting book on practically all phases of the oil industry is stated to be written chiefly for the lay reader, but it covers its subject so comprehensively that it should also prove of general interest to persons connected with the oil industry. The book is concisely and readably written and contains abundant references to the literature. It begins with a brief account of the geology of petroleum, followed by a discussion of leasing and regulations for obtaining leases in different states of the U. S. and in various foreign countries. After this comes a concise treatise of methods of production and then the oil fields of the entire world are each briefly described. Next follows a discussion of the manner of transportation, storage and marketing of crude oil, after which ensues a short description of the natural gas industry. Then the author takes up the refining of oil, laying special emphasis on cracking. The book concludes with an interesting account of the growth and development of the large oil corporations of the world, and with a discussion of future of the oil industry.

PARKER D. TRASK.

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SCIENTIFIC NOTES AND NEWS

J. F. Kemp, of Columbia University, and his wife have recently sailed for Europe prior to attending the International Geologic Congress in Spain.

D. F. Hewett, of the U. S. Geological Survey, left on March 12th for Greece. He will go via Italy and Sardinia to Spain to attend the meetings of the International Geologic Congress.

H. C. Boydell, of the Mass. Institute of Technology, recently lectured before the Geological Club of Yale University on the subject of colloids and ore deposits.

H. G. Ferguson, of the U. S. Geological Survey, and Mrs. Ferguson sailed on April 24th to attend the International Congress in Spain.

Alan M. Bateman, of Yale University, and Mrs. Bateman sail for Spain early in May to attend the International Geologic Congress at Madrid.

Arthur Keith, of the U. S. Geological Survey, is on a short leave of absence to deliver a course of lectures at the University of Texas.

W. D. Burton, geologist for the Northern Peru Mining and Smelting Company at Trujillo, died in Peru on March 16th. He was a graduate of the University of British Columbia and of the Mass. Institute of Technology.

J. V. W. Reynders is in Asia on business connected with the American Caucasian manganese ore concession.

W. T. Thom, chief of the fuel section of the U. S. Geological Survey, is giving a course of lectures on coal, petroleum and oil shale before the geological department of Princeton University.

Percy E. Barbour, assistant secretary of the American Institute of Mining and Metallurgical Engineers, is now connected with the St. Joseph Lead Company's exploration department, making his headquarters in New York City.

William H. Kobbe has taken up consulting work in connection with his work for the Texas Gulf Sulphur Company, in order to broaden his research investigations into sulphur and its products.

Harvey S. Mudd, of Los Angeles, Calif., has returned after some time spent in London, England, and six months of examination work on the Isle of Cyprus.

Hugh D. Miser, state geologist of Tennessee, gave an illustrated address on erosion in the San Juan Canyon, Utah, at the University of Cincinnati on March 10th.